IMPACTS OF ENVIRONMENTAL LOADS ON A JACK-UP OFSHORE STRUCTURE

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Impacts of Environmental Loads on a Jack-up Offshore Structure

By

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Project Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

AP. Dr. Saied Saiedi

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Sanam Aghdamy

ABSTRACT

Due to natural depletion of oil/gas reserves in shallow water depths and also continually increasing the demand for producing these natural resources, steadily more emphasis has been given to design Jack-up structures that can be used in deeper water as well as harsher environment with longer operational periods. This final year project aimed to investigate the impacts of environmental loads (caused by wave, wind and current) on the major reactions (total base shear force and overturning moment) of a typical jack-up offshore platform. In order to perform this research, two real-life jack-up structures were selected and analyzed using SACS structural analysis package. The first selected jack-up structure is called West Prospero which is located at Malaysia's Jerneh and Tapis fields, off the east coast of peninsular Malaysia and the second structure is called MSL model which is designed for Central North Sea environmental condition. To ensure a sound application of the commercial software (SACS), a simple in house computer program facilitating the manual calculations of the total base shear was developed. Toward verifying the analysis outcomes and better understanding of the way in which offshore structures react to environmental forces, some laboratory experiments were carried out on scaled physical model of West Prospero. Given the large approximations involved, the comparison of the experimental results with the computerized calculations showed acceptable similarity for the base shear. The results of sensitivity analysis revealed that the majority of base shear and overturning moment is caused by wave forces. It was shown that the shear force is more sensitive to wave height than to other wave parameters or to diameter of members. However, for the overturning moment the dominant parameter could be wave height or wave period depending on the range of the relative change of the respective factors. The relative increase of members' diameter brings about a low relative change in the overturning moment but a high change in the base shear.

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CHAPTER 1
INTRODUCTION

This dissertation report is the details of the author's Final Year Project (FYP) as an undergraduate civil engineering student at Universiti Technologi PETRONAS. This chapter is dedicated to introduction and explanation of the project topic, "***Impacts of environmental loads on jack-up offshore structure***". It includes: (1) problem statement and (2) objectives of the work.

1.1. Problem Statement

The offshore disaster rate involving jack-ups has exceeded that of other offshore installations. (Young *et al.* (1984); Sharples *et al.* (1989); Leijten and Efthymiou (1989); Boon *et al.* (1997)). It can be understood that the number of failures is increasing as the demand for using this type of offshore structures in deeper water and harsher environment has increased. Furthermore, in some region and for specific purposes, the Jack-up structures must be designed to operate at one site for long periods which also increase the failure risks. These factors have initiated several researches to be performed in these areas. It is crucial to perform new studies to improve the understanding of behaviour of Jack-up structures, enhance the existing knowledge, develop new technologies and hence reduce the number of accidents which can potentially cause great loss of life and properties.

Besides, in Malaysia the design of offshore structures is mostly done by the international companies. In line with Malaysian national development plan, there is an effort to improve the local expertises in offshore engineering area and decrease the dependency. Study about jack-up structures which is one of common type of offshore structures may help to understand and disseminate the knowledge in this area.

1.2. Objectives of Study

Objectives of this FYP project are to:

1. Develop a simple computerized frame work for base shear forces.
2. Investigate the environmental impacts on the stability of a Jack-up structure.
3. Simulate the response of a real-life Jack-up structure under varying environmental loads using SACS.
4. Develop an experimental setup for physical modeling of a Jack-up structure.
5. Compare the experimental results with the computerized calculations.

CHAPTER 2
LITERATURE REVIEW

As it is mentioned earlier, Jack-ups were originally designed for use in the relatively shallow waters (Carlsen *et al.*, 1986). Progressively by increasing demand, the more emphasis has been given to design this type of offshore structure in relatively deeper water and harsher environment with longer one-site operation period. As a result, several researches have been initiated by companies, institutes and individuals. This chapter reviews some of individual studies that have been published on offshore structure response to environmental forces.

L. Manuel et al. (1998) carried out a research on the response of a jack-up rig to random wave loading. Steady current and wind load effects were also included. The effects of varying the relative motion assumption (in the Morison equation) and of varying the bottom fixity assumptions were investigated. Time domain simulations were performed using linearized as well as fully nonlinear models for the jack-up rig. Comparisons of response statistics were made for two sea-states. The results showed that hydrodynamic damping caused the rms response to be lower in the relative Morison case. The absence of this source of damping in the absolute Morison force model gave rise to larger resonance dynamic effects. The different support conditions studied were seen to significantly influence extreme response estimates. In general, stiffer models predicted smaller rms response estimates. The choice of the Morison force modelling assumption (i.e., the relative versus the absolute motion formulation) was seen to have at least a secondary role in influencing response moments and extremes.

Cassidy et al. (2001) investigated long-term extreme response statistics of a jack-up offshore platform subjected to ocean waves. They concentrated particularly on the long-term response due to random ocean waves and on work-hardening plasticity models used for spud-can response. A methodology for scaling of short-term statistics was presented in a numerical experiment for an example jack-up and central North Sea location. The difference in long-term extreme response statistics due to various footing assumptions was reported. Results for two environmental load conditions were described (one excluding and one including wind and current effects) and the role of sea-state severity in the variation of short-term extreme response statistics was also highlighted.

G. Vlahos (2001) performed a series of experiments conducted on a scaled three-legged jack-up unit model, equipped with spudcan footings, on soft clay. The objective was to investigate jack-up behaviour, particularly soil–structure interaction and load sharing among the spudcan footings. A scale model jack-up unit for testing at unit gravity were designed and assembled at the University of Western Australia. The model rig was subjected to combined vertical and horizontal loads at the hull level, resulting in combined vertical, moment and horizontal loads at the footings. The physical tests which incorporated two distinct stages of installation and pushover, explored the load redistribution among the spudcan footings, hull and footing displacements at failure, and ultimate system capacity. The data obtained through these tests gave some indication of the amount of rotational foundation fixity that spudcan footings on clay can provide.

MSL Engineering Ltd. conducted a study on sensitivity of jack-up reliability to wave-in-deck calculation for the Health and Safety Executive (2003). A sensitivity study was performed using the MSL wave-in-deck model (in MathCAD format) to assess the importance of a number of variables on the wave-in-deck loads generated, such as degree of hull inundation, aeration level at the top of the wave and wave theory used. Dynamic pushover analyses were performed on a detailed non-linear model of a typical Jack up structure using the USFOS structural analysis package. The hull structure was modelled such that it attracted the wave-in-deck loads in accordance with the MSL model. The pushover analyses were based on a 10,000-year wave. A sensitivity study was performed to investigate the effects that hull inundation, foundation modelling, wave theory and structural response to a preceding wave have on dynamic response to the extreme wave. It was found that wave-in-deck loads cause a significant increase in environmental loading once inundation occurs. The horizontal loading at the front face of the hull leads to a large increase in global overturning moment once inundation occurs. A main finding is that the upward wave-in-deck loading which is principally caused by buoyancy of the hull, leads to a large decrease in vertical loading on the windward legs, with leg tension possible for inundations of 2m. The reduced vertical foundation load tends to decrease the moment capacity of the spudcan foundation, leading to greater leg/hull moments and global displacements.

Chai (2005) performed a numerical analysis of fixed offshore structure subjected to environmental loading in Malaysian water. He focused on a response of a typical Jacket offshore structure to environmental loading. A four legs steel jacket offshore structure at the Sotong field in South China Sea was selected as the case study. This jacket was modelled as a space frame using ANSYS finite element package. Meanwhile, the estimation of extreme value of environmental parameters based on data on Malaysia waters was carried out using MINITAB. Response of the structure under environmental loading was performed using static analysis. Interaction ratios of the members were computed based on API RP2A–WSD (1993) using MATLAB. The sensitivity of the jacket structure to variation in design parameters was investigated. The results of the sensitivity research showed that the base shear is most sensitive to changes in wave height while overturning moment is greatly influenced by wave period. The nonlinear finite element analyses had been used to determine the ultimate load capacity of a complex joint, which one of the member of the joint had high stress utilization when assessed using API RP2A–WSD (1993). The analyses showed that multiplanar effects significantly enhance the joint capacity partly due to the restraint afforded by the presence of braces in other planes and partly due to the effect of loads in the other braces counteracting those in the critical brace. Supplementary analyses had indicated that the analysis gives a close prediction of characteristic strength when compared directly with the joint test database.

Saiedi et al. (2007) studied the impact of environmental factors on the forces in an offshore platform. They emphasized to analyze the impact of environmental factors on the forces in a fixed bottom supported offshore platform using a simple in-house computer program called FABSOSEL (Force Analysis of Bottom supported Offshore Structures under Environmental Loads). A braced caisson which is a type of Minimum Facility Platform (MFP) in Davy field in South North Sea was selected as the case study to get insight into sensitivity of fixed offshore platforms to environmental parameters. The breakdown of base shear force in to three loads pertaining to wave, current and wind revealed that wave has greatest impact on base shear of that platform (about 85%). The study of the values and ratios of wave action of wave to the members, wind action to the members above the water level and current action to the various members indicated that among the wave parameters (height, length and period), the wave height causes the greater impact. The results obtained in this research showed that 50% increase in wave height will double the total force. Whilst 50% decrease in wave period leads to reduction of total wave force by only 10%. The results also showed that the impact of height on total force acting on the structure is more significant than the impact of member dimensions.

CHAPTER 3

THEORY PART I: INTRODUCTION TO OFFSHORE STRUCTURES

This chapter covers the definition of offshore structures, historical development of offshore structures in exploration of petroleum reserves, classification of offshore oil platforms with short description of each type and their applications and detailed description of jack-up offshore structure.

3.1 Definition of Offshore Structures

The term "offshore structures" may refer to variety of structures in ocean such as marine and commercial ships, heavy-lift crane vessels used to support the field development operations, barges, tugs and pipelines, but in this project the focus is on offshore platforms which are used for exploration and production of oil/ gas from under seabed.

Offshore platform as it is shown in Figure 3.1 is a house for workers and machinery required to drill and produce petroleum in the ocean. These structures do not have fixed access to onshore and consequently they are needed to remain in position in all weather condition.

Figure 3.1 An offshore platform

3.2 Historical Development of Offshore Structures

The world's first offshore oil wells ware drilled in 1890s in offshore Summerlands, California in Pacific Ocean and offshore Baku, Azerbaijan in Caspian Sea. However, in 1920s earlier platforms had been constructed and installed in Lake Maracaibo. The first offshore oil rig is constructed and installed by Humble Oil Co. in 1938. It was in approximately one mile offshore in Gulf of Mexico and in water depth of 18m.

However the birth of the offshore industry, as it is today, is commonly considered as in 1947 when kerr-McGee completed the first successful offshore well in Gulf of Mexico in 15ft (4.6 m) of water off Louisiana. The drilling derrick were supported on a 38ft by 71ft (11.6m by 21.6m) wooden decked platform built on 16.24-in (61 cm) pilling driven to the depth of 104ft (31.7 m). Since successful installation and use of first oil offshore platform, offshore industry has observed many novel and innovative structures placed in deeper waters and harsh environments. By 1975, platforms were successfully constructed and installed in water depth of about 144m. From 1975 to 1978 offshore engineers had succeeded to design and install platforms in water depth of about 312m which was more than double of previous platforms.

Today there are more than 10,000 offshore platforms with variety of types and sizes which have been constructed and installed worldwide [4]. Some of these platforms are located in ultra deep water and very sever environment such as Petronius compliant platform operated by Chevron Corporation and Marathon in Gulf of Mexico. This platform has 609.9m (2001ft) height and it is the world's tallest free-standing structure.

3.3 Classification of Offshore Structures

Offshore structure may be classified into two major types of bottom-supported and floating. This section provides explanation of the characteristics and applications of each type of offshore structures and also comparison between bottom-supported and floating structures.

3.3.1 Floating Offshore Structures

Floating structures may have different degrees of compliancy. They could be defined as being either Neutrally buoyant or Positively buoyant.

3.3.1.1 Neutrally buoyant structures

Floating structures such as Semi-Submersibles, Spars and Drillships are called Neutrally buoyant structures. These structures are allowed to have six degrees of freedom or in anther word they are dynamically unrestrained.

Semi-submersible platform (Figure 3.2) is multi-legged platform with large deck. The legs of this structure are interconnected bellow the water level with buoyant members. This kind of structure can be moved from place to place. During drilling, the structure is tethered to the sea bed to keep it in position. Semi-submersible can be used in depths from 180 to 1,800 m.

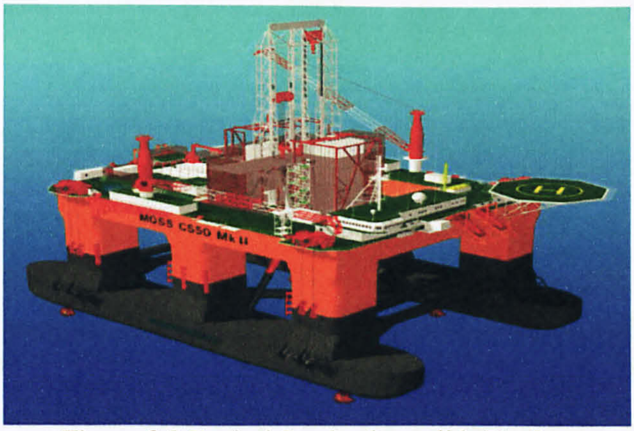


Figure 3.2 Typical Semi-submersible Platform

Spar platform (Figure 3.3) in concept, is a large deep cylindrical floating caisson which is anchored to the bottom of ocean by conventional mooring lines. Its buoyancy is used to keep the facilities above water level. Spar generally has three different configurations:

1. "Conventional" which is one-piece cylindrical hull
2. "Truss spar" where the midsection is composed of truss elements connecting the upper buoyant hull (called a hard tank) with the bottom soft tank containing permanent ballast
3. "Cell spar" which is composed of multiple vertical cylinders.

Figure 3.3 Typical Spar structure

Floating production system (Figure 3.4) is large ship equipped with processing facilities and anchored to the bottom of ocean at location for a long time. The main types of floating production system are FPSO (floating production, storage, and offloading system), FSO (floating storage and system offloading system), and FSU (floating storage unit).

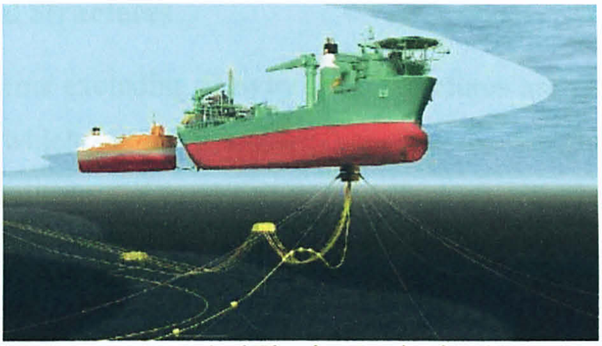


Figure 3.4 Typical Floating Production System

3.3.1.2 Positively buoyant structures

Floating structures such as Tension Leg Platforms (TLPs) are called positively buoyant structures. These structures are tethered to the seabed and heave-retrained. They are structurally rigid with respect to global compliancy and compliancy is achieved with mooring system. Figure 3.5 shows a TLP .This positively buoyant structure is used in water depths up to about 6,000 feet (2,000 m).

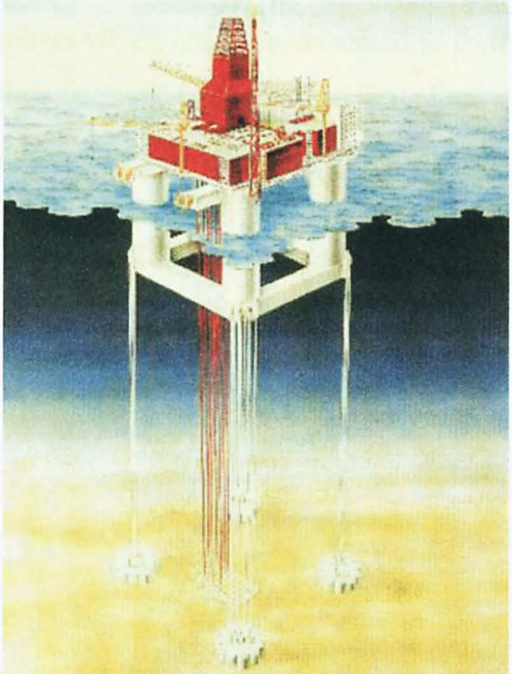


Figure 3.5 Typical Tension-Leg platform

3.3.2 Bottom- Supported Structures

Bottom-supported platforms excluding Gravity Base structures are mostly made of welded tubular steel members which act as a truss supporting the weight of machineries and equipments needed for drilling and production as well as environmental forces caused by wind, wave and current. Bottom-founded structures are either "fixed" or "compliant".

3.3.2.1 Bottom-Supported Fixed Structures

Bottom-supported structures are referred as "fixed" when their lowest natural frequency of flexural motion is above the highest frequency of significant wave excitation. They act as a rigid body which resist full dynamic forces of the environment.

The most common bottom-supposed fixed structures are jacket structures, gravity base structures and jack ups.

Steel jacket structure (Figure 3.6) is one of the most common types of offshore platform. It consists of steel tubular members which are interconnected to form a space frame. This type of structure typically has four to eight legs founded on piles which are extended to the seabed and battered to achieve stability against toppling in waves. Jacket structure is generally used for water depth up to about 500-600 ft (150-180m).

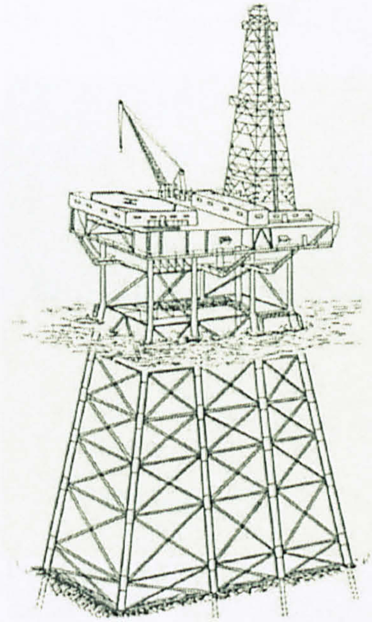


Figure 3.6 Typical Steel Jacket Platform

Gravity Base structure (Figure 3.7) is made of concrete. This type of structure is placed on seabed and held in position by the weight contained in its base. Hence it does not require further help from piles anchors. Gravity Base structures are suitable for water depth up to 300m.

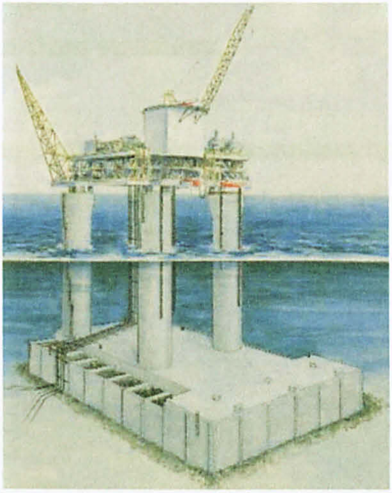


Figure 3.7 Typical Gravity Base Structure

Jack-up platform (Figure 3.8) is typically a three-tubular-legged structure with a deck supported on them. This type of structure is designed to move from place to place. At drilling site, the legs are anchored to the sea bed and the deck is jacked up on these legs above water level. Jack-up structure is used for moderate depth of water. This type of platform is discussed in detail in section 3.4.

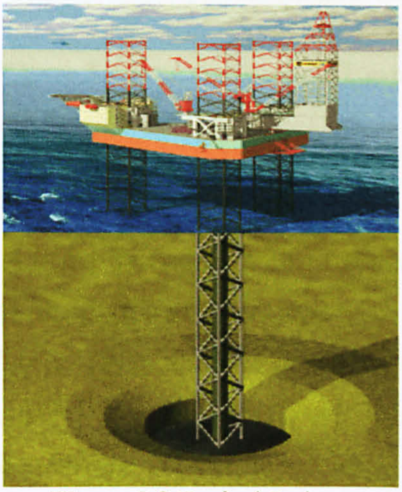


Figure 3.8 Typical Jack- up

3.3.2.2 Compliant Structures

Bottom supported structures are referred as "Compliant" when their lowest natural frequency is below the energy in the waves. These structures deflect under environmental forces but as a result the magnitude of the dynamic loads is greatly reduced. This characteristic of compliant structures allows designing bottom-founded structures for water depths, which is not practical and economical for fixed structures.

The most common type of compliant structure is compliant tower (Figure 3.9). It is flexible framed structure supported by pile foundations. This type of structure is generally used for moderate water depth up to 600m.

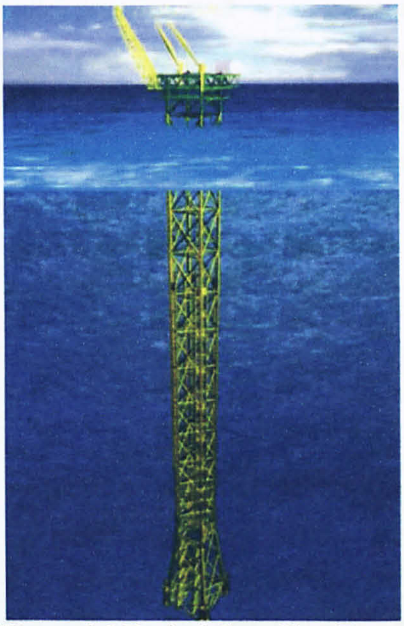


Figure 3.9 Typical Compliant Tower

3.3.3 Floating vs. Fixed Offshore Structures

Fixed structures differ from floating structures both in appearance and structural systems (Figure 3.10). The ways that fixed offshore structures are constructed, transported and installed, type of excitation forces which they are subjected to and their response to these excitation forces are different for floating structures. Table 3.1 summaries the main differences between bottom-founded and floating structures.

Table 3.1 Bottom- Founded vs. Floating Structures (Chakrabati, 2005)

Function	**Bottom- Supported**	**Floating**
Payload support	Foundation-bearing capacity	Buoyancy
Environmental loads	Resisted by strength of structure and foundation	Restrained by vessel inertia and stability, mooring strength
Construction	Tubular space frame	Plate and frame displacement hull
Installation	Barge transport and launch, upend, piled foundations	Wet or dry transport, towing to site and attachment to pre-installed moorings
Regulatory and design practices	Oil industry practices and government petroleum regulations	Oil industry practices and government petroleum regulations and Coast Guard & International Maritime regulations

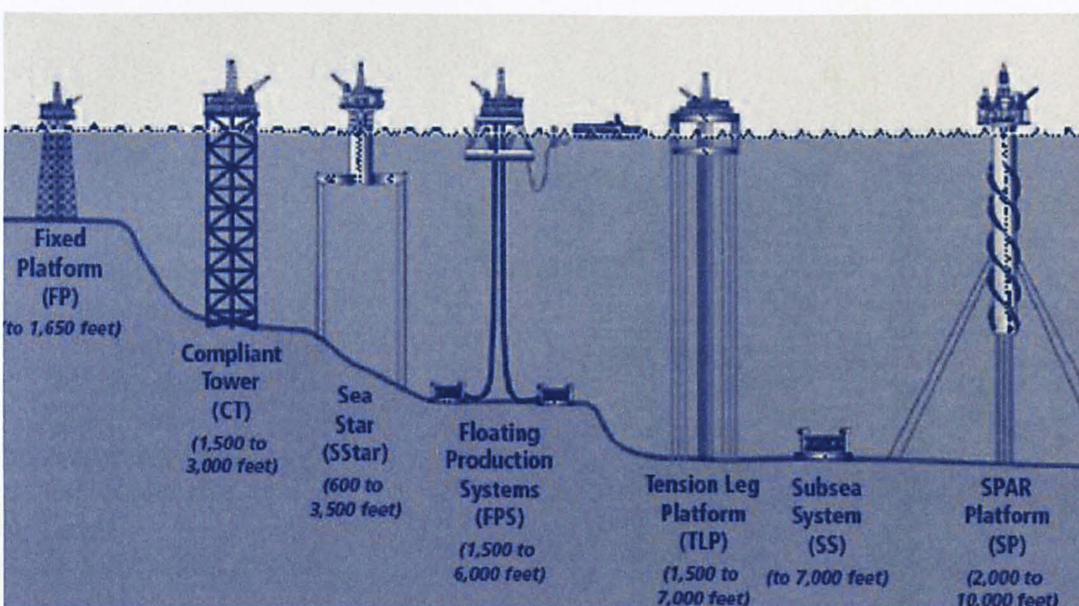


Figure3 10 Various offshore platforms and their feasible water depth range

3.4 Jack-up Offshore Structure

This section is provided to explain about jack-up offshore structures which the main concern in this project. This section contains definition of jack-up structures, historical development of this type of fixed offshore platform, components of jack-up structures and their functions and , basic configurations of jack-up and modes of operation of jack-up platform.

3.4.1 Definition of Jack-up Structures

As it is mentioned earlier, jack-up structure (Figure 3.11) is a type of bottom-supported fixed Structures which is typically consists of a buoyant triangular platform founded on three truss-work legs. This type of structure is mobile and during operation, it rest on the bottom of ocean with the help of spud cans or a mat connected to the vertically movable legs. A typical jack-up structure is capable of working in harsh environment (Wave heights up to 80 ft, wind speed in excess of 100 knots) in water depth up to 500ft [7].

a) Spud cans
b) Elevating racks
c) Legs
d) Gear units
e) Drilling derrick equipment
f) Accommodation
g) Helicopter pad
h) Cranes
i) Nearby jacket platform

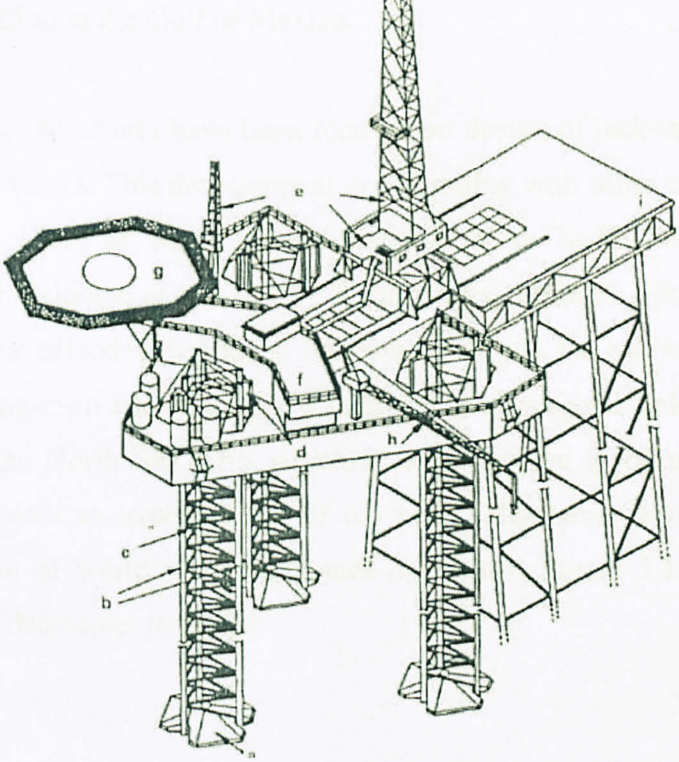


Figure 3.11 A typical jack-up structure

This type of structure is mainly used for exploration drilling with on-site operating duration of few months. They can also be used for development and production with operating time of one year or more.

3.4.2 Historical Development of Jack-up Structures

The earliest reference to a jack-up platform is in the description of a United States patent application filed by Samuel Lewis in 1869 (Veldman et al.(1997)). The first unit that utilize the jack-up concept was Delong Mc Dermott No.1 which was constructed in 1954. It consists of a buoyant member (pontoon) with number of tubular legs that could be moved vertically. Once at site, the legs of the structure could be lowered and then pontoon rest on the seabed using the same principle as present jack-up.

In 1956 R.G. LeTourneau, a former entrepreneur in earthmoving equipment (Ackland, 1949), revolutionised the design of jack-ups by reducing the number of legs to three (Stiff et al. (1997)). The first jack-up unit operated by Marathon LeTourneau was Zepata's "Scorpian", used in water depths up to 25 m in the Gulf of Mexico.

Since construction of first jack-up units, the efforts have been focused on design of jack-up structures which can be used in deeper waters. This development is continuing with some of the largest units being used in about 120m of water in the relatively harsh North Sea environment (Hambly et al. (1991) and Veldman et al. (1997)). Furthermore, some of jack-up units are now designed to operate for extended periods at one site, mostly in the role of production unit. An example of the long-term use of jack-ups is in the Siri marginal field development in the Danish sector of the North Sea. This structure is being used in 60 m water depth as a production platform with an expected life of ten years (Baerheim et al. (1997)). Figure 3.12 shows distribution of world's operating jack-ups whilst Figure 3.13 shows distribution of world's operating deepwater jack-ups.

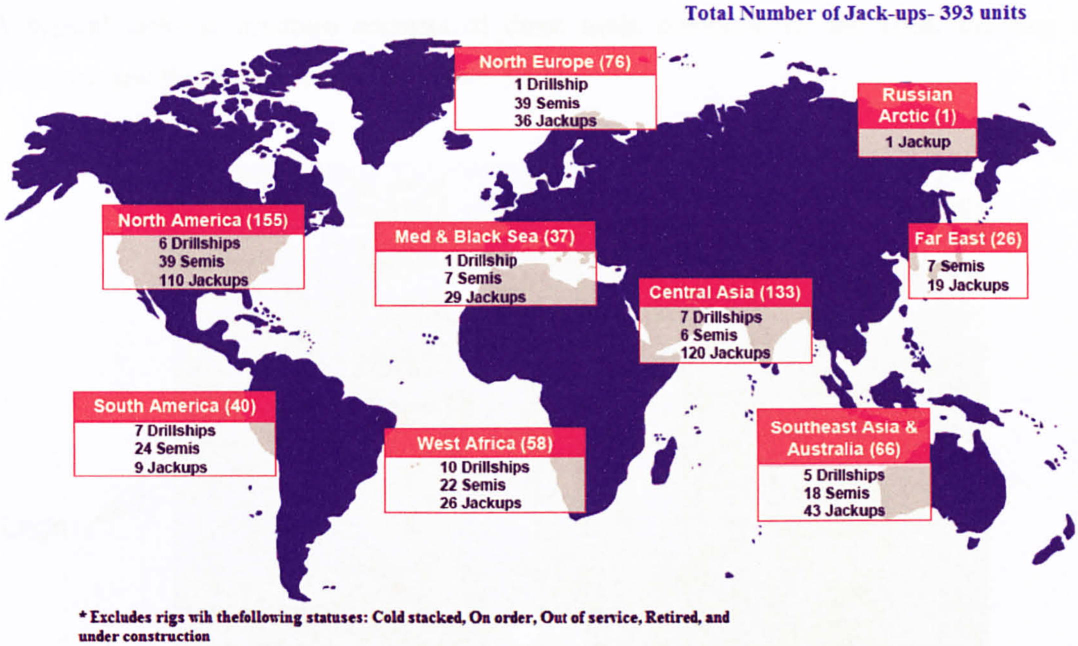


Figure 3.12 Distribution of world's operating jack-ups as August 2007 [23]

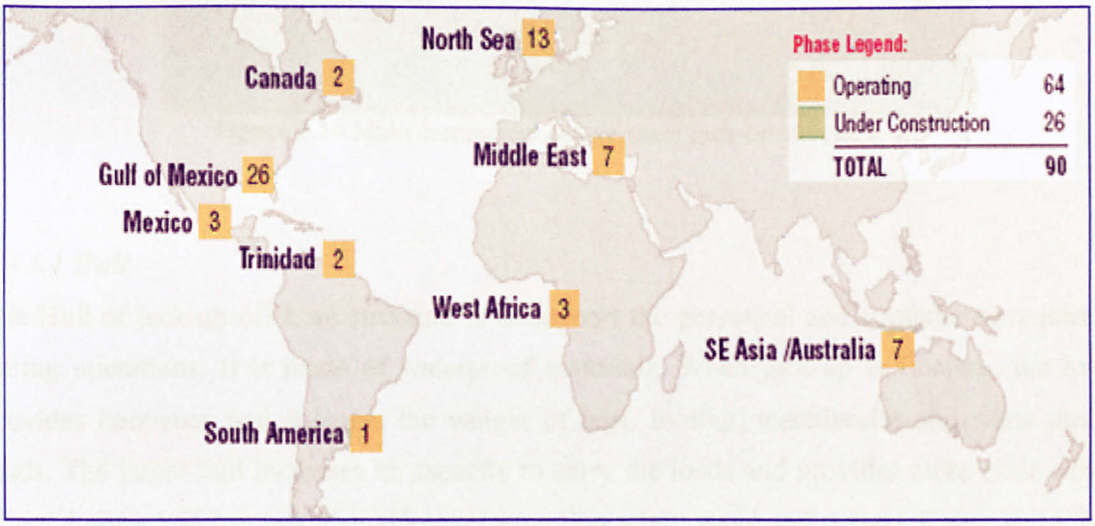


Figure 3.13 Distribution of world's operating deepwater jack-ups as July 2005 [23]

3.4.3 Components of Jack-up Platforms and Their Functions

A typical jack-up structure consists of three main components; the Hull, the Leg and Footings, and the Equipments (see Figure 3.14).

Figure 3.14 Main components of a typical jack-up structure

3.4.3.1 Hull

The Hull of jack-up offshore structure is to support the personnel and equipments required during operations. It is made of waterproof materials. When jack-up is floating, the hull provides buoyancy and supports the weight of legs, footing, machineries and some other loads. The larger hull increases its capacity to carry the loads and provides more clear work space. Larger hull has negative effect on attracting wind, wave and current forces since the larger hull has more weight and therefore requires more elevating jacks with higher capacity to elevate and hold the units.

3.4.3.2 Legs and Footings

The legs and footings of Jack-up structure are made of steel materials. They support the hull when the unit is elevated and provide stability to resist lateral loads. The footings are necessary to increase soil bearing area and hence reducing required soil capacity.

The legs of a Jack-up Unit may extend over 500 ft above the surface of the water when the Unit is being towed with the legs fully retract [18]. The legs, depending on thier dimensions usually have the most significant impact on floating stability of units. The units with larger size and therefore heavier weight have less afloat stability. It should be mentioned that the larger legs and footing also influence the level of environmental loads attraction when the structure in elevated mode. The larger legs and footing generally result in greater loads which the structure are exposed to.

3.4.3.3 Equipments

Typically there are three types of equipments on the Jack-up unit which are:

1. Mission equipment
2. Marine equipment
3. Elevating equipment

"Mission equipments" are those equipments on the Jack-up structure which are vital for unit to perform its tasks. Examples of these equipments are derricks, mud pumps, mud piping, drilling control systems, production equipment, cranes, combustible gas detection and alarms systems, etc.

"Marin equipments" are those equipments on the Jack-up units which are not related to the Mission equipments. Examples of these equipments are main diesel engines, fuel oil piping, electrical power distribution switchboards, lifeboats, radar, communication equipment, etc.

"Elevating equipments" are those equipments on the Jack-up units which are crucial for the structure to raise, lower and lock-off the legs and hull.

3.4.4 Basic Jack-up Configurations

The jack-up structures may have a verity of configurations which are mostly differing in design and operational philosophy. The basic differences between Jack-up structures are discussed as follows:

3.4.4.1 Independent Leg Jack-ups vs. Mat-Supported Jack-ups

Independent leg Jack-ups have a set of single footings which are called spud cans, spud tanks or doughnuts (see Figure 3.15). Spud cans are conical shape structures that have both upward and downward slopes. This type of Jack-up units has many advantages. Among all advantages, the greatest advantage is that they can be used on a veracity of seabed conditions and they do not need sensitive ballasting sequences or equipments.

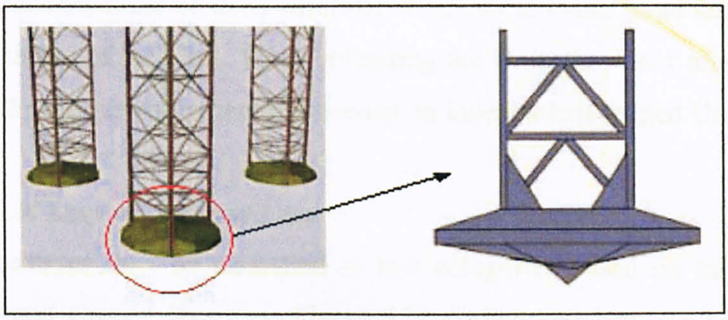


Figure 3.15 Independent spud can footing

Mat-supported Jack-ups are another type of jack-ups which the legs are rested on a mat footing (see Figure 3.16). Mat is generally rectangular in shape and contains buoyancy chambers.

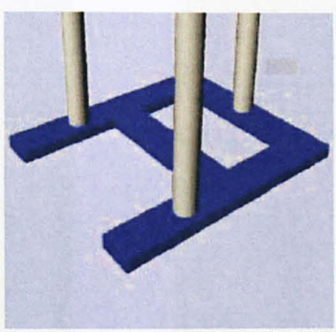


Figure 3.16 Mat-supported footing

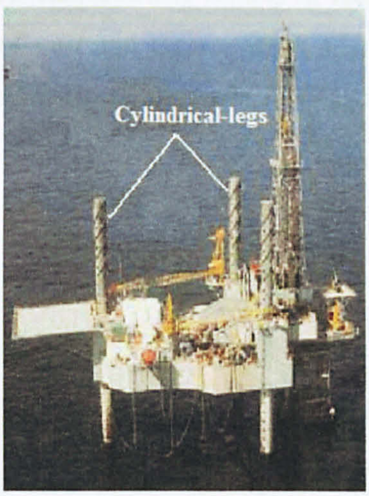
Mat footings have two major advantages. These advantages are:

1. Due to larger size of footing, they exert lass bearing pressure on the soil which they rest on it. This chrematistic is helpful when the soil beneath the structure is soft.
2. Due to provision of considerable buoyancy caused by footing, this type of Jack-up structure has more capacity to carry the verity of loads in floating mode.

Besides the advantages, Mat-supported jack-ups have some disadvantages. This type of Jack-up cannot be used on the slopes as well as bottoms where there are some obstructions. Furthermore, during transition from afloat to on-bottom operation, the mat must be flooded. This flooding sequence must be done carefully so as not to cause large heeling moments or loss of afloat stability of the Unit. When refloating the Unit, the water must be pumped out of the mat, which requires equipment not needed on independent-legged Units.

3.4.4.2 Cylindrical Legs vs. Trussed Legs

The Jack-up structures may be classified in two categories based on their types of legs; cylindrical legs and trussed legs (see Figure 17). Cylindrical legs are hollow steel tubes which can be used for water depth up to 300ft. For water depth of 300ft or greater, usually trussed legs are used.



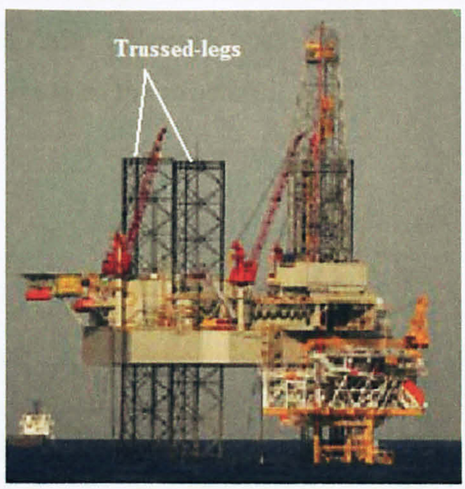


Figure 3.17 Cylindrical legs vs. trussed legs

The cylindrical legs are beneficial in shallow water since they are smaller and have less deck area. They usually are less complicated and hence required less experience to design and construct them.

The trussed legs are composed of braces and chords. The truss shape of legs allows optimizing the steel consumption which results in lighter legs and reduction of drag forces act on the structure.

3.4.4.3 Three-Legged vs. Four-Legged Jack-ups

Most of Jack-up units do not have more than four legs (Figure 3.18) but there are some units with more than four legs [18].

The three- legged units are in form of triangle. They eliminate the need to build extra leg and in addition they can carry more loads in floating mode. They have lighter weigh and need less maintenances since they require less elevating units, but the disadvantages is that they require preload tankage.

The four-legged structures are in the form of rectangle. They need little or no preload tanks. The latest characteristic results in less piping and equipments which in turn results in less weight of unit and clearer work space on the deck. However, these positive effects may decrease due to extra leg which cause addition loads on the structure.

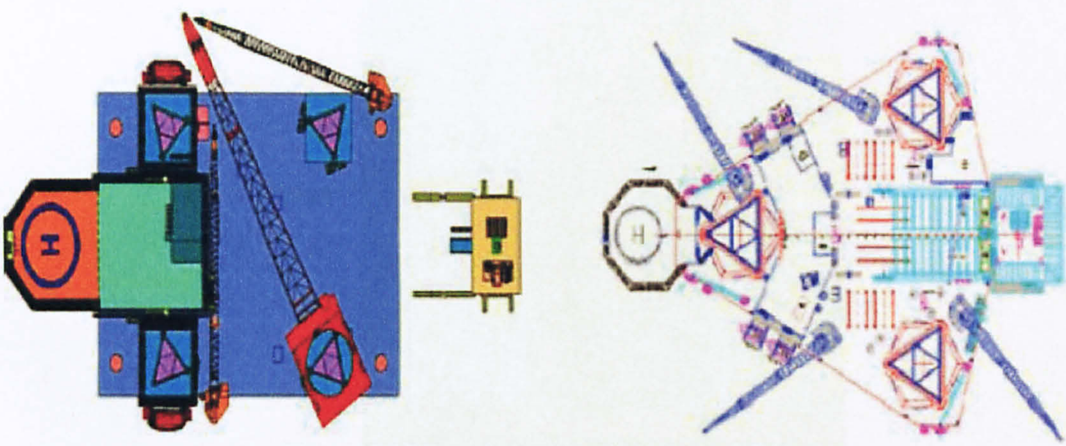


Figure 3.18 Four-legged vs. three-legged Jack-ups

3.4.4.4 Three-Chorded Legs vs. Four-Chorded Legs

Any trussed legs jack-p units operating today have either three or four main vertical structural members called chords. Basically, the advantages and disadvantages of three- versus four-chorded legs are comparable in nature to those of three- and four-legged jack ups such as overall weight, drag loads and redundancy. The only exception is that they do not affect preloading procedures.

3.4.4.5 Elevating System

Any jack-up unit must have mechanism for lifting and lowering the hull. Pin and hole system is the most basic type of elevating system, which allows for hull positioning only at discrete leg positions. Nevertheless, most of jack-up units in use today are equipped with a Rack and Pinion system (Figure 3.19) for continuous jacking operations. There are two basic jacking systems: floating and fixed. The floating system tries to equalize chord loads by using relatively soft pads, whereas the fixed system allows for unequal chord loading while holding. Electric and hydraulic powers are two power sources for fixed jacking systems. Both systems have the ability to equalize chord loads within each leg. A hydraulic-powered jacking system achieves this by maintaining the same pressure to each elevating unit within a leg.

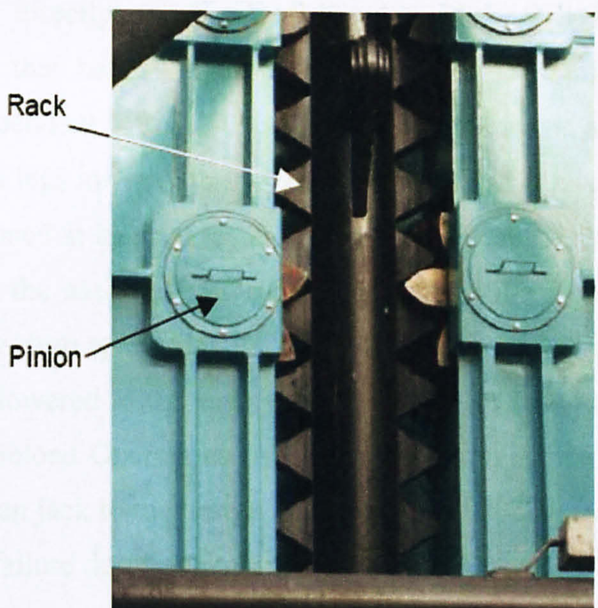


Figure 3.19 Rack and Pinion system

3.4.5 Modes of Operation of Jack-up Units

Jack-up units operate in three major modes: transit from one location to another, elevated on its legs, and jacking up or down between afloat and elevated modes.

The transit mode occurs when a jack-up unit must be transported from on place to another. In this mode, the unit's legs are raised to ensure they clear the seabed during tow. Jack-up unit can be transported either by floating it on its own hull (wet tow) or by being carried as cargo on the deck of another vessel (dry tow) is to be transported from one location to another.

Upon completion of the transit mode, the jack-up unit is called to be in the arriving on location mode. In this mode, the unit is prepared for elevated mode. If an independent leg jack-up unit is going to be operated next to a fixed Structure, or in a complex area with bottom restrictions, the jack-up unit will often be positioned temporarily away from its final operation location. This is called "Soft Pinning". This process involves lowering one or more legs until the bottom of the spud can(s) just touches the soil. The objective of this is to provide a "Stop" point in the arriving on location process. Whether a Unit stops at a Soft Pin location, or positioned directly on the final location, they will have some means of positioning the unit so that ballasting or preloading operations prior to jacking up can commence. For an independent leg jack-up unit, holding position is accomplished by going on location with all three legs lowered so the bottom of the spud can is just above the seabed. When the Unit is positioned at its final location, the legs are lowered until they can hold the rig on location without the assistance of tugs. Mat type jack-up units are either held on location by tugs, or they drop spud piles into the soil. A mat Unit will jack the mat to the. Once the mat has been lowered to the seabed, the hull will be jacked out of the water. The Unit then proceeds to preload Operations. All Independent leg Units must perform preload operations before they can jack to the design air gap. This preloading reduces the probability of a foundation shift or failure during a Storm.

Once preload operations are completed, the unit is jacked up to its operational air gap. Whenever the unit reaches its operational air gap, the jacking system is stopped, the brakes set, and leg locking systems engaged. At this time the Unit is ready to begin operations.

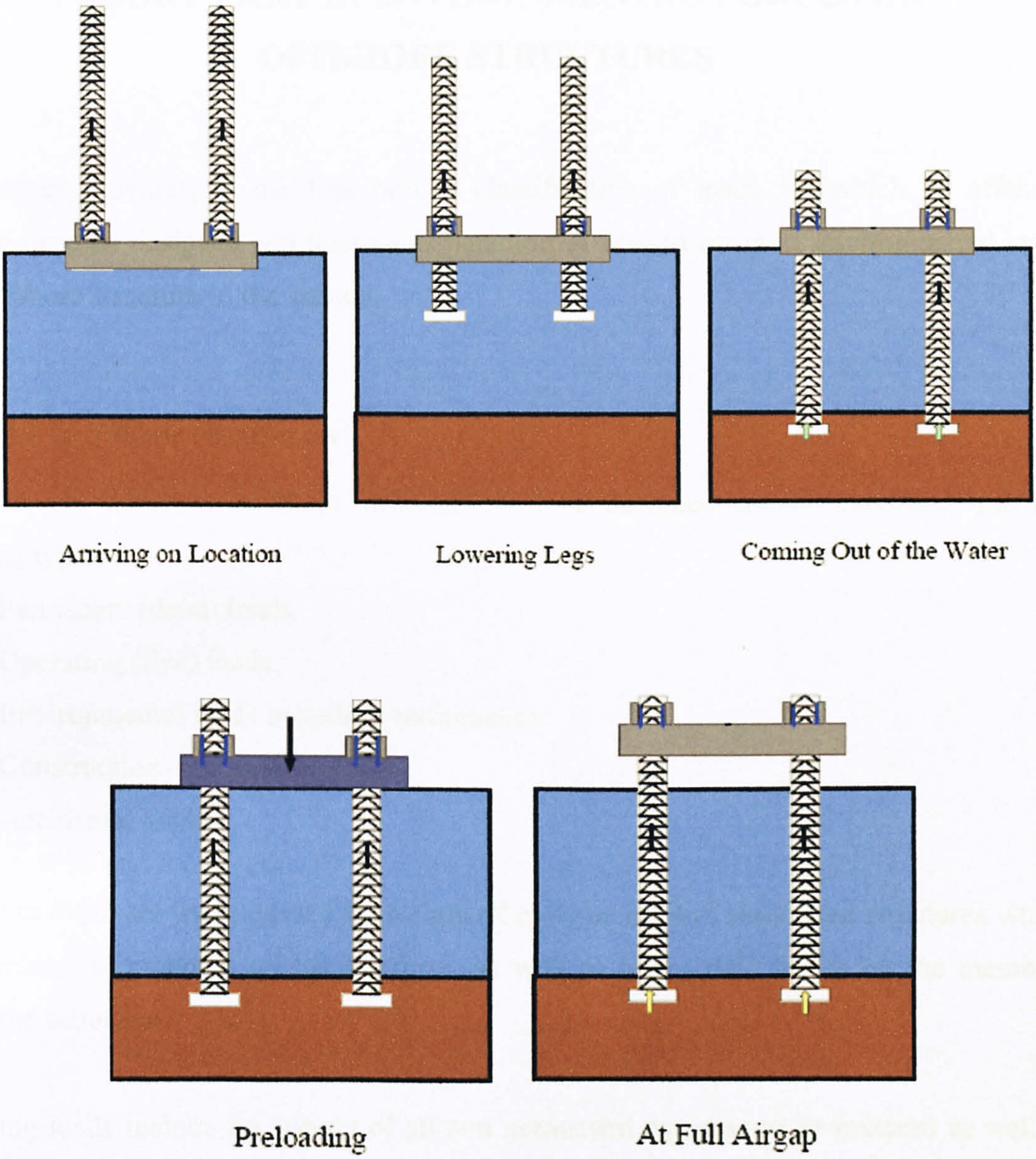


Figure 3.20 Modes of operation of jack-up unit

CHAPTER 4

THEORY PART II: ENVIRONMENTAL FORCES ON OFFSHORE STRUCTURES

This chapter provides, in the first part, a classification of loads for which an offshore structure must be designed and then an explanation of how to compute environmental loads on an offshore structure in the second.

4.1 Loads on Offshore Platforms

The loads for which an offshore structure must be designed can be classified into the following types:

1) Permanent (dead) loads.
2) Operating (live) loads.
3) Environmental loads including earthquakes.
4) Construction - installation loads.
5) Accidental loads.

Permanent loads are those caused by weight of equipments and associated structures which are permanently mounted on the platform, as well as hydrostatic forces on the members bellow the waterline.

Operating loads include the weight of all non permanent equipments or material as well as forces generated during operation of equipments.

The environmental loads are those caused by wind, wave, current and other environmental factors and they will be explained in details in next section.

The construction-installation loads are temporary loads and arise during fabrication and installation of the platform or its components.

Accidental loads are loads which may occur as a result of accident or exceptional circumstances like collision with vessels or fire.

It should be pointed out that among all types of loads which are described above, environmental loads, especially wave have the most influence in design of offshore structures.

4.2 Environmental Loads on Offshore Platforms

As it is mentioned in earlier section, environmental forces are those caused by environmental factors such as wind, waves, current, tides, earthquakes, temperature, ice, sea bed movement, and marine growth. Their characteristic parameters, defining design load values, are determined in special studies on the basis of available data. According to US and Norwegian regulations (or codes of practice), the mean recurrence interval for the corresponding design event must be 100 years, while according to the British rules it should be 50 years or greater.

In order to understand the effect of environment on the structure and resulting forces experienced by the structure, certain non-dimensional parameters play an important role. These parameters are summarized in Table 4.1.

Table 4.1 Important non-dimensional quantities

Parameters	**Formula**
Reynolds number	$\mathrm{Re} = u_o D / \upsilon$
Keulegan-Carpenter number	$KC = u_o T / D$
Relative surface roughness	$e = K / D$

In the formulas in Table 4.1, Re is Reynolds number, u_o is water particle velocity amplitude, υ is kinematic viscosity of water, T is the wave period, e is relative roughness parameter, K is surface roughness parameter, D is member diameter and KC is Keulegan-Carpenter number. The Reynolds number and the Keulegan-Carpenter number determine the importance of the drag force on the structure. The surface roughness affects the forces on a small structure. The roughness of a surface is mainly due to the marine growth on the submerged part of a structure. In particular, the values of drag and inertia coefficients are affected significantly by roughness of the structure surface.

4.2.1 Current Loads

Current can be generated by environmental phenomena such as tides, circulations and storm. Current is generally assumed to be time-invariant and it is represented by mean value. It should be pointed out that although the current does not change with time but its magnitude does change with depth. The force caused by current on the surface of structure can be calculated as follows:

$$F = \frac{1}{2}\rho C_D A U^2 \tag{4.1}$$

Where, ρ is fluid density, A is structure projected area normal to the flow, U is uniform flow velocity and C_D is drag coefficient. The drag coefficient C_D has been revealed to be a function of Reynolds number, Re which is in turn a function of mean current velocity and member diameter. The drag coefficient for a smooth stationary circular cylinder in a steady flow is shown in Figure. 4.1.

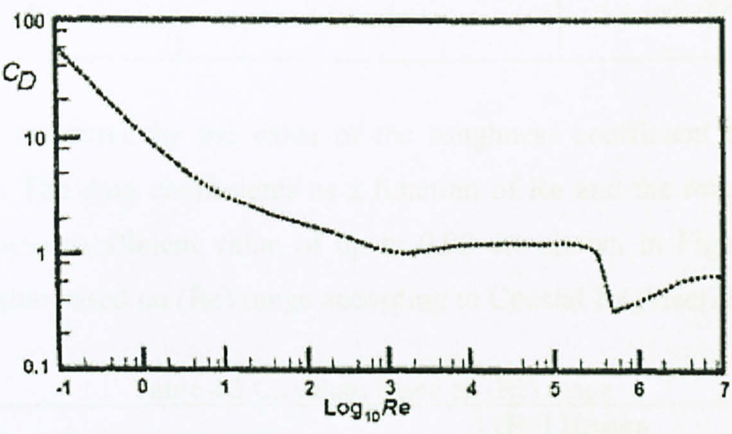


Figure 4. 1 Drag coefficient for a smooth circular cylinder in steady flow [4]

In practice, the surface of the offshore structures in operation mode is not smooth. This roughness can be due to several reasons. The appendages that are attached to the structure may introduce the irregularities. The marine growth attached to the surface of structure near the ocean surface also causes the surface roughness. This type of roughness increases the effective size of structure and hence increases the total projected area of structure exposed flow and as a result, the drag force act on the structure is increased. Moreover, if the surface of the structure is not smooth, the roughness moves the point of flow separation on the structural member and the corresponding wake behind the structure, resulting in an increase in pressure gradient between the upstream and down stream of the structure and finally causes a change in the drag coefficient.

The API guideline recommends a 1.5 in. growth on members for depths from 0 to 150 ft below the surface. Whilst according to N-003, NORSOK [15], belonging to Norway practiced for the North Sea, in the absence of more accurate data and if regular cleaning is not planned, marine growth thickness can be taken from Table 4.2. This thickness may be assumed to increase linearly up to the given values over 2 year period after the structure has been placed in the sea. Roughness height may be taken as 20mm below +2m.

Table 4.2 Norwegian standard for marine growth on members

Water depth, m	56-59°N	59-72°N
Above +2	0	0
+2 to -40	100 mm	60 mm
Under -40	50 mm	30 mm

The roughness is measured by the value of the roughness coefficient e = K/D which is introduced earlier. The drag coefficients as a function of Re and the roughness coefficient, K/D for a roughness coefficient value of up to 0.02 are shown in Figure. 4.2. Table 4.3 contains the C_D value based on (Re) range according to Coastal Engineering Manual [17].

Table 4.3 C_D values based on (Re) range

C_D	**(Re) Range**
C_D=1.2	$R_e < 10^5$
C_D decreases from 1.2 to 0.6-0.7	$10^5 < R_e < 4 \times 10^5$
C_D =0.6-0.7	$R_e > 4 \times 10^5$

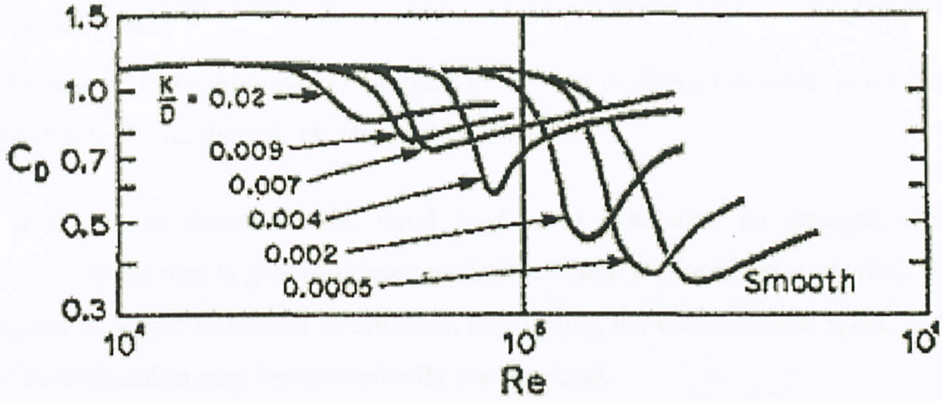


Figure 4. 2 Drag coefficient for a rough circular cylinder in steady flow [4]

In addition to the drag force which is parallel to the flow, another force is generated by current in traverse direction to the flow. This force is generated due to asymmetric pressure distribution caused by uneven formation of vortices behind the structure. This force is referred to as lift and it is calculated as follows:

$$F = \frac{1}{2}\rho C_L A U^2 \tag{4.2}$$

Where C_L is lift coefficient and the rest of the symbols are as defined in Equation.4.1. The lift coefficients obtained from experiments are shown in Figure 4.3 as functions of *Re* values. There is considerable scatter in the experimental data. The two curves in Figure 4.3 provide the upper and lower ranges of experimental C_L and its value in a particular case can only be determined approximately.

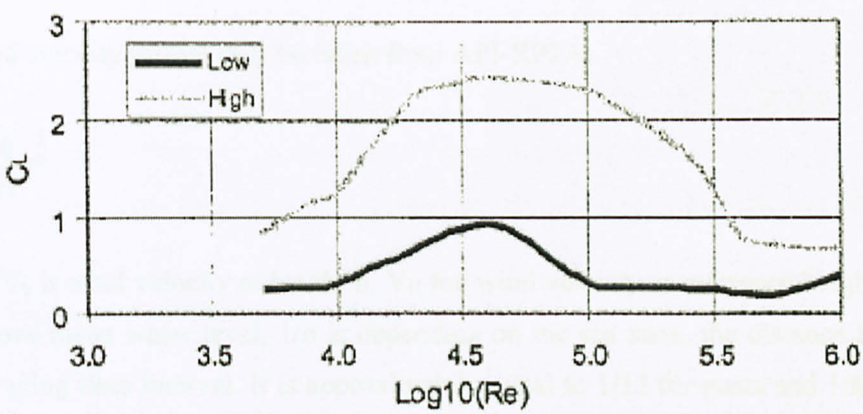


Figure 4. 3 Lift coefficient for a smooth circular cylinder in steady flow [4]

4.2.2 Wind Loads

Wind loads act only on portion of a platform which is above the water level including any equipment, housing, derrick, etc. located on the deck.

The first step to determine the wind load is to determine its strength, direction and frequency. Wind rose is generally used to find out these characteristics of wind. Wind rose is a diagram in which statistical information concerning the direction and speed of the wind at a particular location may be conveniently summarized.

In the standard wind rose a line segment is drawn in each of possibly eight compass directions from a common origin. The length of each segment line is proportional to the frequency of wind which blows from that direction. Each part of a given segment has a thickness which indicates the wind speed in that direction.

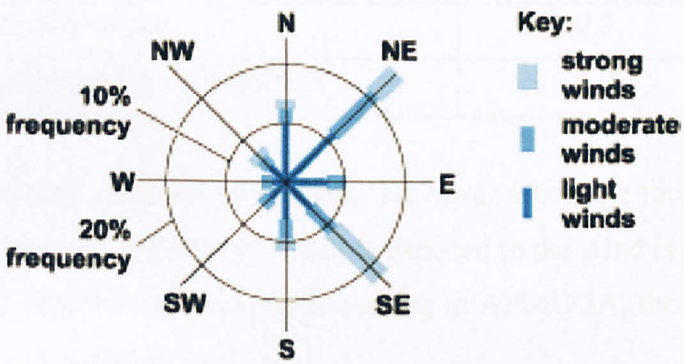


Figure 4. 4 Wind Rose

The wind velocity profile may be taken from API-RP2A:

$$\frac{V_h}{V_H} = \left(\frac{h}{H}\right)^{\frac{1}{n}} \qquad \textbf{(4.3)}$$

Where, V_h is wind velocity at height h, V_H the wind velocity at reference height H, typically 10m above mean water level, 1/n is depending on the sea state, the distance from land and the averaging time interval. It is approximately equal to 1/13 for gusts and 1/8 for sustained winds in the open ocean.

Using design wind velocity V (m/s), the static wind force F_w (N) acting perpendicular to an exposed area A (m^2) can be computed as follows:

$$F_w = \frac{1}{2}\rho V^2 C_s A \tag{4.4}$$

Where, ρ is wind density (ρ ~1.225 Kg/m^3), C_s is the shape coefficient. The recommended shape coefficients by the API Guidelines (2000) for normal wind approach are summarized in Table 4.4.

Table 4.4 Summary of recommended shape coefficients by the API Guidelines (2000)

Item	C_s
Beams	1.5
Sides of buildings	1.5
Cylindrical sections	0.5
Total projected area of platform	1.0

The wind force is generally assumed to be static. However when the ratio of height to the least horizontal dimension of the structure which is exposed to the wind is greater than 5, the structure may possibly sensitive to wind and according to API-RP2A, the dynamic effect of the wind must be taken in to account.

4.2.3 Wave Loads

The wave loading on offshore structure is usually the most important among all environmental loads for which an offshore structure must be designed. Wave forces are caused by motion of water due to the waves which are generated by the action of wind, gravitational pull of moon/sun (tides), changes in atmospheric pressure or displacement such as land slide and earthquake.

Determination of wave loads requires solving two interrelated problems which are:

1. Computation of sea state using an idealized wave surface profile and wave kinematics from appropriate wave theory.

2. Computation of wave forces on each member of structure and the structure as a whole, from fluid motion.

4.2.3.1 Sea State

The wave theories that are used to determine the wave kinematics are based on the assumption that the waves are regular and remain invariant in their properties from one cycle to the next. However in actuality the ocean waves are random in nature and hence they must be described by their statistical properties.

The two most important parameters that quantify the state of sea are a characteristics height and characteristics period. There are numerous quantities which can be used to describe the height of the sea such as the mean height, the route- mean- square height and the most probable largest height. Of these, the most commonly used is the significant height that is written as H_s (or $H_{1/3}$) and is defied as the average of the highest one-third waves in the given wave period. Significant wave height can be computed as follows:

$$H_{\frac{1}{3}} = \frac{3}{N}\sum_{N}^{\frac{N}{3}} H_i \tag{4.5}$$

Where N is the number of individual wave height H_i.

Like characteristic wave height, characteristic wave period can also be described using different values such as the mean period, average zero-crossing period and peak period. If N_z is the number of zero upcrossing in the record and T_s is the total length of time in the record, the mean zero-upcrossing period, $\overline{T_z}$ is obtained from

$$\overline{T_z} = \frac{T_s}{N_z} \tag{4.6}$$

Alternatively, if the total number of crests in the record is N_c, then the mean crest period is obtained from:

$$\overline{T_c} = \frac{T_s}{N_c} \tag{4.7}$$

4.2.3.2 Wave Theory

Wave theories are used to compute the kinematics of waves such as water particle velocities and accelerations, and the dynamic pressure as functions of the surface elevation of the waves. In these theories, the waves are assumed to be long crested and characterized by following parameters: (see Figure 4.5)

- Wave height (H)
- Period (T)
- Water depth

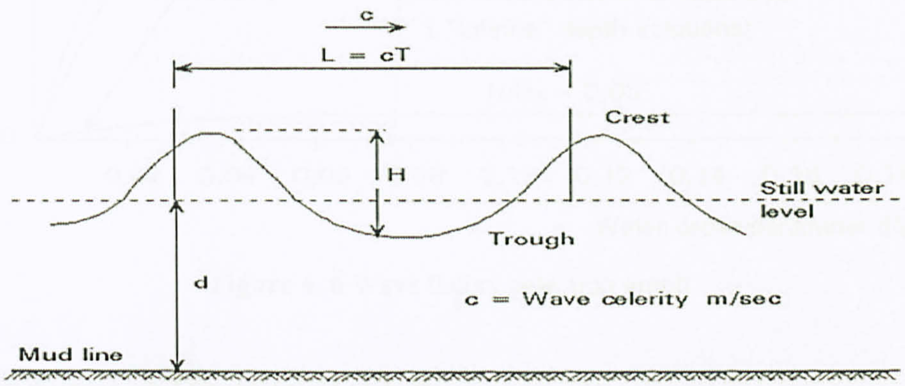


Figure 4. 5 Wave Characteristics

Numerous wave theories with different level of complexity have been developed which each of them is appropriate for a specific range of wave parameters. The most common theories are: the linear Airy theory, the Stokes fifth-order theory, the solitary wave theory, the cnoidal theory, Dean's stream function theory and the numerical theory by Chappelear (Refer to Appendix A for basic equations used in Linear Airy theory). The graph shown in Figure 4.6 can be consulted to decide on the most appropriate theory.

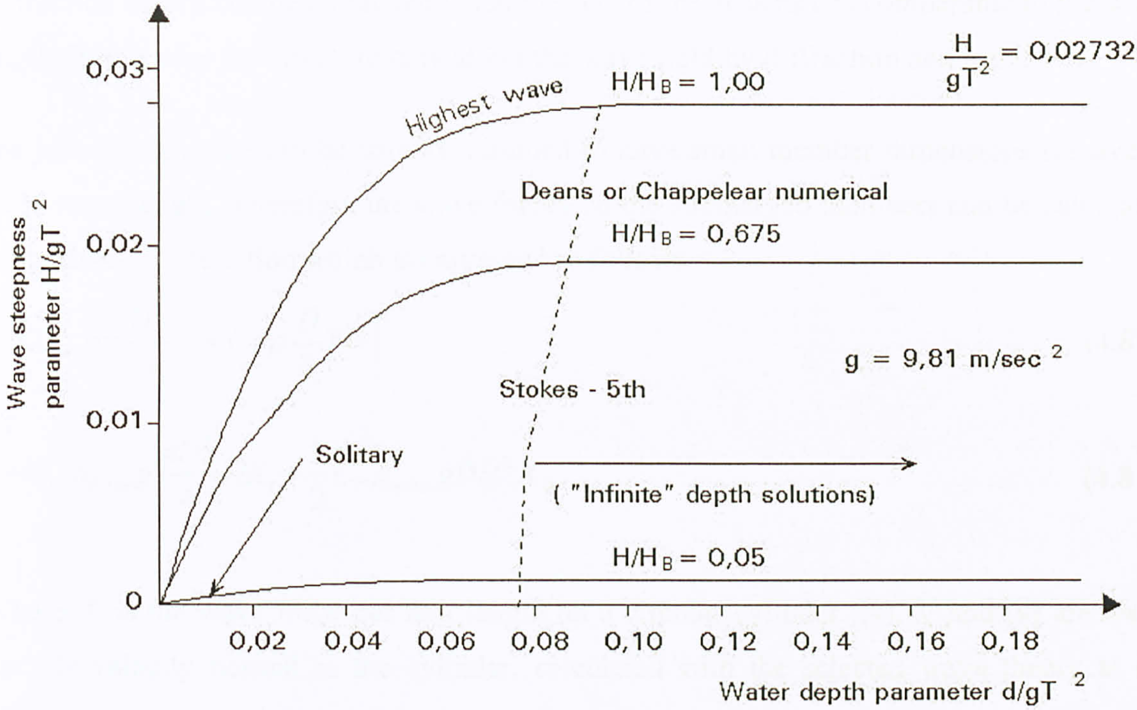


Figure 4. 6 Wave theory selection graph

4.2.3.3 Wave Forces on Structural Members

The wave forces on offshore structures can be computed using the following theories:

- Morison equation
- Froude-Krylov theory
- Diffraction theory

Morison equation is applicable when the drag force is significant. This is usually happened when a structure is small compared to the water wave length (D/L < 0.2, where D is the member diameter and L is the wave length). The Morison equation assumes that the wave force applied on the structure is composed of inertia and drag forces which are linearly added together.

Froude-Krylov theory can be applied when the drag force is small and the inertia force predominates, but the structure is still comparatively small.

Diffraction theory can be employed when the size of the structure is comparable to the wave length. In this case the structure may affect the wave field by diffraction and reflection.

The jack-up structure can be usually assumed to have small member dimensions relative to water wave length. Therefore the wave forces on the submerged members can be calculated using Morison's equation which is expressed as follows

$$F = C_M \rho \pi \frac{D^2}{4} \dot{V} + C_D \rho \frac{D}{2} V|V| \qquad \textbf{(4.8 a)}$$

Or

$$F = C_M \rho_{Water} g \frac{\pi D^2}{4} H K_i + \frac{1}{2} C_D \rho_{water} g D H^2 K_D \qquad \textbf{(4.8 b)}$$

Where, F is the wave force per unit length on a circular cylinder (N), V and |V| are water particle velocity normal to the cylinder, calculated with the selected wave theory at the cylinder axis (m/s), $\dot{V}$ is water particle acceleration normal to the cylinder, calculated with the selected wave theory at the cylinder axis (m/s^2), ρ is the density of water (kg/m^3), D is the member diameter, including marine growth (m) and C_D and C_M are drag and inertia coefficients, respectively. The K_i and K_d in Equation (4.8b) Can be calculated using the following formulas:

$$K_i = \frac{1}{2} \tanh\left(\frac{2\pi d}{L}\right) \qquad \textbf{(4.9)}$$

$$K_D = \frac{1}{4} n \qquad \textbf{(4.10)}$$

Where n can be calculated using the following formula:

$$n = \frac{C_g}{C} = \frac{1}{2}\left(1 + \frac{4\pi d / L}{\sinh[4\pi d / L]}\right) \qquad \textbf{(4.11)}$$

The values of C_D and C_M depend on the wave theory used, surface roughness and the flow parameters. According to API-RP2A, C_D is ranging from 0.6 to 1.2 and C_M is varying from 1.3 to 2. The graphs shown in Figure 4.7 and Figure 4.8 can be used to estimate the value of C_D and C_M. These graphs are obtained from a fluid oscillation test done by Sarpkaya 1976. The β-value in these two graphs is the ratio of (Re/KC). Table 4.3 could be employed to estimate the C_D value while Table 4.5 can be consulted to determine the C_M value according to Coastal Engineering Manual.

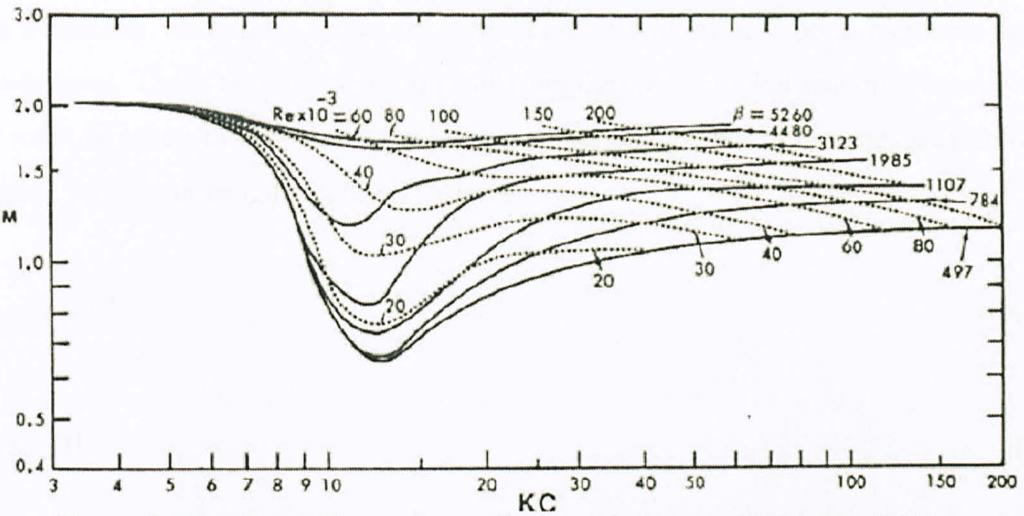


Figure 4.7 Inertia coefficient from a fluid oscillation test (Sarpkaya, 1976)

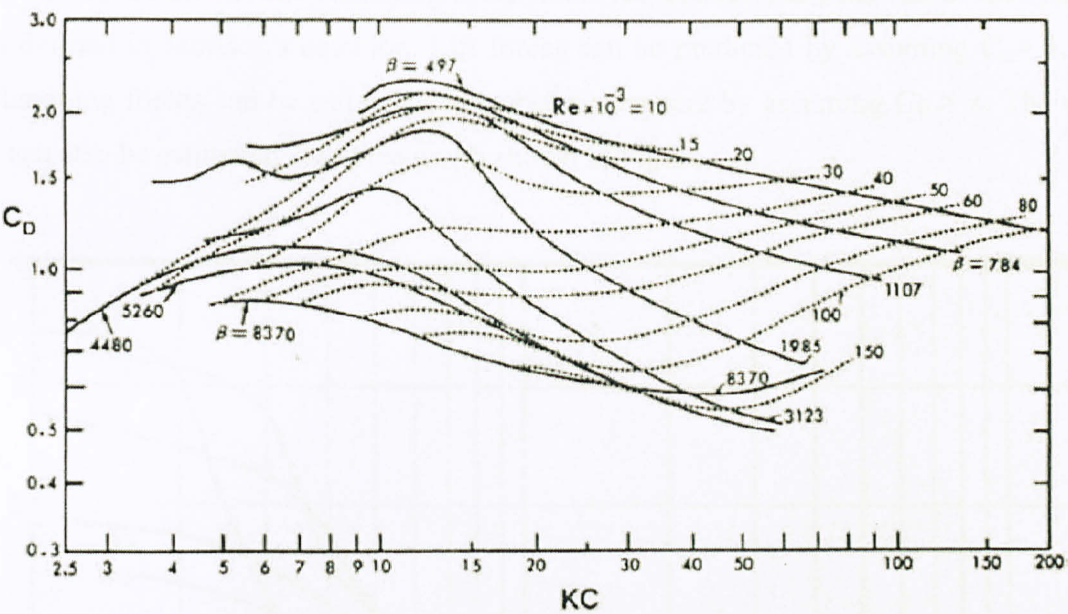


Figure 4. 8 Drag coefficient from a fluid oscillation test (Sarpkaya, 1976)

Table 4.5 CM values based on Re range

C_M	(Re) Range
$C_M = 2.0$	$R_e < 2.5\times10^5$
$C_M = 2.5 - R_e/5 \times10^5$	$2.5 \times10^5 < R_e < 5 \times10^5$
$C_M = 1.5$	$R_e > 5 \times10^5$

Besides the wave forces that can be computed using Morison's equation, there are two other forces caused by wave which are lift force (F_D) and slamming force (F_S). Lift force is perpendicular to the member axis and the fluid velocity v and is related to the vortex shedding frequency. Slamming forces are applied on beneath of horizontal members near the mean water level. These two forces are typically negligible for global response computations but they must be taken in to account for local member design. For a member section of unit length, these forces can be calculated as follows:

$$F_L = (\frac{1}{2})\rho C_L D V^2 \tag{4.12}$$

$$F_S = \frac{1}{2}\rho C_s D V^2 \tag{4.13}$$

Where C_L, C_S are the lift and slamming coefficients respectively, and the rest of the symbols are as defined in Morison's equation. Lift forces can be predicted by assuming $C_L > 1.3\ C_D$ and slamming forces can be estimated for tubular members by assuming $Cs > \pi$. The value of C_L can also be estimated using the graph shown in Figure 4.9.

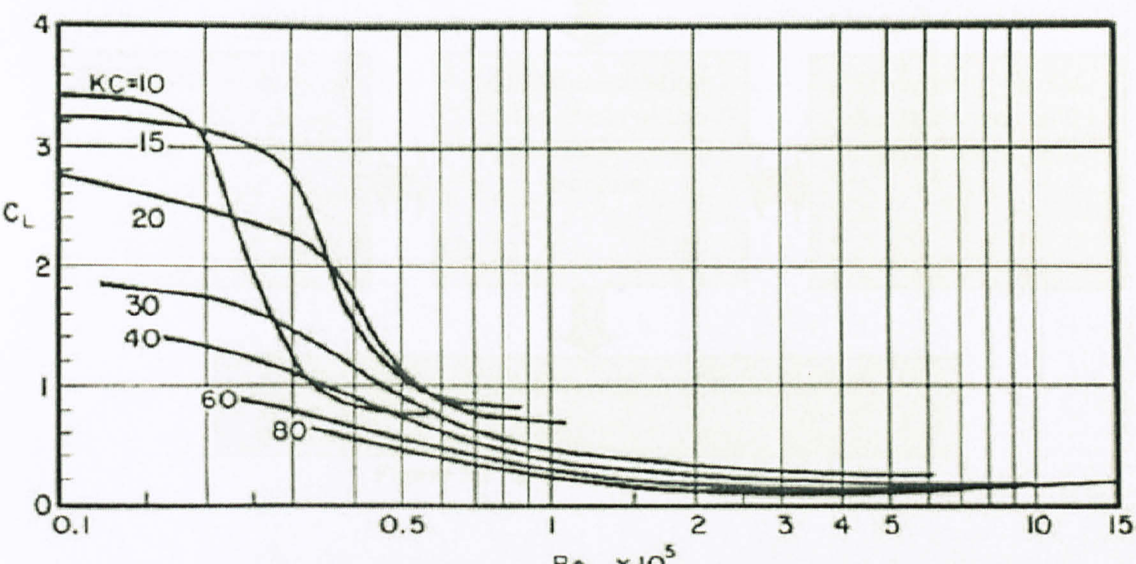


Figure 4. 9 Lift coefficient from a fluid oscillation test (Sarpkaya, 1976)

CHAPTER 5
METHODOLOGY/PROJECT WORK

This chapter is allocated to explain the methodology that the author was used to achieve the objectives of the project. Each section of this chapter describes a stage of the project. The summary of project stages is shown in Figure 5.1.

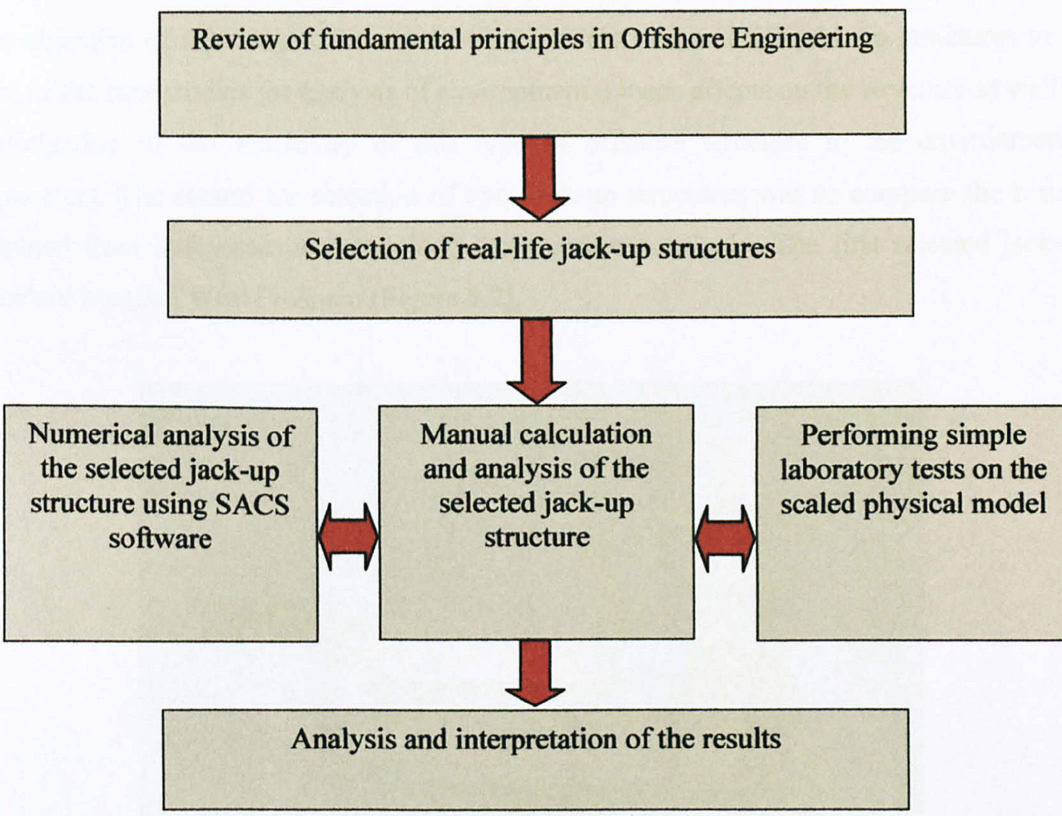


Figure 5.1 Summary of project stages

5.1 Review of Fundamental Principles in Offshore Engineering

At the first stage of the research, a preliminary study about offshore structures and loads, in particular environmental loads, act on them was done. Some literatures that have been published in the area of author's research topic;" Impacts of environmental loads on jack-up offshore structure" were reviewed. The purpose of this stage was to get more acquainted to the fundamental knowledge about offshore engineering before entering to the next stages of the research. The summary of this study is reflected in chapter 2, chapter 3 and chapter 4 of this report.

5.2 Selection of Real-Life Jack-up Structures

The objective of this stage of research was to select two real-life jack-up structures to be used as the case studies for analysis of environmental loads effects on the structure as well as investigation of the sensitivity of this type of offshore structure to the environmental parameters. The reason for selection of two Jack-up structures was to compare the results obtained from both cases and conclude more comprehensively. The first selected jack-up structure is called West Prospero (Figure 5.2).

Figure 5. 2 West Prospero jack-up

The West Prospero (previously known as Seadrill 4) owned by Seadrill Ltd. is a Jack-up type of offshore structure. It can operate at water depth up to 350 ft (106.68 m) and drill down to approximately 30,000 ft (9144m). It is designed by Keppel Fels KFELS B and built by Keppel Fels at the Keppel Fels, Singapore shipyard and then delivered to Malaysia in 2007 by Seadrill for gas development projects in Malaysia's Jerneh and Tapis fields, off the east coast of peninsular Malaysia (Figure 5.3).West Prospero is scheduled to drill ten production wells under a one-year charter contract with Exxon Mobil Malaysia [22].

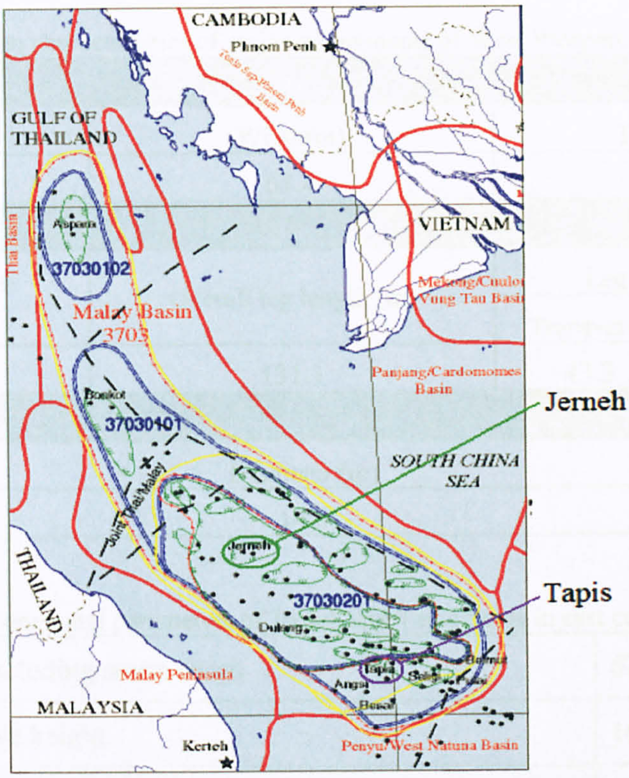


Figure 5. 3 Location of Jerneh and Tapis fields

West Prospero has four-chorded three-trussed legs which are founded on the independent spudcan footings. The type of elevating system is rack and pinion. The characteristics of major components of West Prospero Jack-up structure and environmental parameters of Jerneh and Tapis fields in east coast of peninsular Malaysia are summarized in Table 5.1 and Table 5.2 respectively. It should be mentioned that some of the data related to layout drawings and dimensions of the main members of West prospero jack-up was not available and hence they were assumed in order to proceed to the analysis stage of the project. The parameters that their values were assumed are:

- Diameter of chords: 0.6m
- Diameter of braces: 0.42m
- Length of horizontal braces: 5m
- Vertical spacing between horizontal braces: 7.6m

Table 5.1 The given characteristics of major components of West Prospero Jack-up structure

<table>
<tr><th colspan="4">Hull</th></tr>
<tr><td>Length (m)</td><td>Width(m)</td><td colspan="2">Depth(m)</td></tr>
<tr><td>71.3</td><td>63.4</td><td colspan="2">7.6</td></tr>
<tr><th colspan="4">Leg</th></tr>
<tr><td rowspan="2">Leg penetration (m)</td><td rowspan="2">Overall leg length (m)</td><td colspan="2">Leg spacing (m)</td></tr>
<tr><td>Transverse</td><td>Longitudinal</td></tr>
<tr><td>25.9</td><td>131.1</td><td>43.3</td><td>39.3</td></tr>
<tr><th colspan="4">Spud can</th></tr>
<tr><td colspan="4">Diameter (m)</td></tr>
<tr><td colspan="4">14.3</td></tr>
</table>

Table 5.2 Environmental parameters of Jerneh and Tapis fields in east coast of Malaysia

Water depth including storm surge	67.06 m
Maximum wave height	16.46 m
Period of the 100-year wave	14 sec
Associated current speed at the surface	0.51 m/sec
Maximum wind speed at 10m above SWL	36.01 m/sec
Soil type	Sand

The second selected Jack-up structure is called MSL model. It is a designed Jack-up structure in Central North Sea which has been developed by MSL Engineering Ltd. for the Health and Safety Executive (HSE) United Kingdom to perform a sensitivity study to assess the important factors affecting the loads generated during inundation [10].

The modelled Jack-Up is a three-legged structure with a maximum elevated weight of 12500t. The total weight of the modelled platform is 16500t. The legs are triangular, consisting of three tubular chords spaced at 12.2m and braced at bays of 6.96m with a K-bracing arrangement.. At the bottom of each leg is a spudcan. The overall height of each leg is 146m, and they are spaced approximately 55m apart. The connection between the leg and hull consists of a set of pinions and rigid horizontal guides at the bottom of the hull and at the top of the yoke frame. The hull of the Jack-up is triangular with the length of 80m, width of 72m and height of 12m. The diameter of chords is 0.85m and diameter of braces is assumed to be 0.6m. Table 5.3 contains environmental parameters at Central North Sea.

Table 5.3 Environmental parameters at Central North Sea

Water depth including storm surge	96.6m
Maximum wave height	31.2m
Period of the 100-year wave	17.7 sec
Associated current speed at the surface	0.67 m/sec
Maximum wind speed at 10m above SWL	40.1 m/sec
Soil type	Sand

5.3 Numerical Analysis of Jack-up

At this stage of research, West prospero and MSL Jack-ups were analyzed structurally for its main members by developing a simple computer program and concurrently by simulating the response of the Jack-up structure using an offshore engineering software package, called SACS. The purpose of developing a computer program to analyze the structure was to understand the process of analysis and check the results obtained from SACS software. The Jack-up models were analyzed under different environmental conditions to investigate the changes in the environmental forces with respect to those conditions. The basic environmental variables in this research are as following:

- Wave height
- Member diameter
- Wind speed
- Current speed
- Wave period
- Water depth

The general description about SCAS software required input data and expected output results from this software are explained as following:

SCAS software is developed by Engineering Dynamics, Inc. This software consists of several compatible structural analysis programs which are interfaced to each other to reduce the requirement, for user interaction with the output of one program before input to another. All programs include a full complement of standard engineering defaults in both English and Metric units to simplify input. The relationships between different programs of the system are illustrated schematically in Figure 5.4. All the structural data such as geometry, member dimensions, and material properties together with environmental parameters are generated by input generation program and saved in the common input file. The solution program operates on the input data and generates the common solution file which consists of joint displacements and element internal forces. The post processing program use the information produced in the analysis stage to evaluate the performance of the structure with respect to any of several structural codes. If the structure is not satisfying the code, it can be automatically redesigned. The complete dimensioned structural drawings and bills of materials are automatically produced at the end of process ([6], [11]).

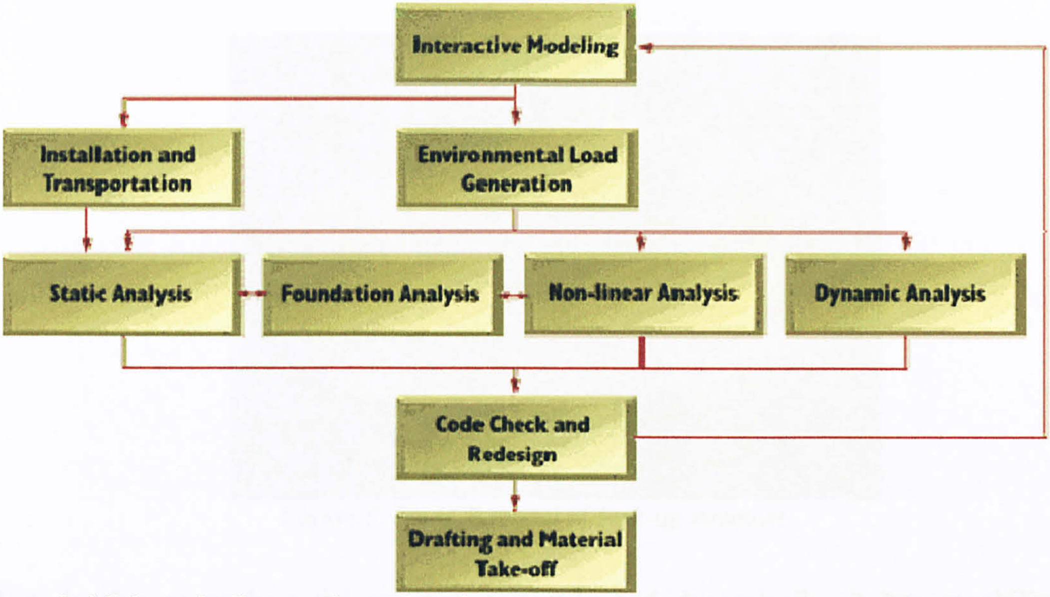


Figure 5. 4 Schematic diagram shows the relationships between different programs of SACS system

SACS has the capability of modelling the structure in 3D interactive environment (Figure 5.5). The Intelligent MDI editor can be used to create the input file easier. It has library of AISC, UK, European, German, and Japanese standard cross – sections. It is able to generate finite element models for a general purpose finite element stress analysis.Wave, gravity, buoyancy, wind, and current load can be generated by SACS software. It is capable of fully implement the API 20th Edition environmental loading. The model definition file for this software consists of:

- Definition of the type of analysis, the mudline elevation and water depth
- Member sizes (member groups and sections).
- Member joints definition.
- Soil data
- Joint coordinates
- Marine growth input
- Inertia and mass coefficients input
- Distributed load surface area definitions.

- Wind area definitions
- Load cases, which will include dead and live loading, environmental loading, crane loads, etc.

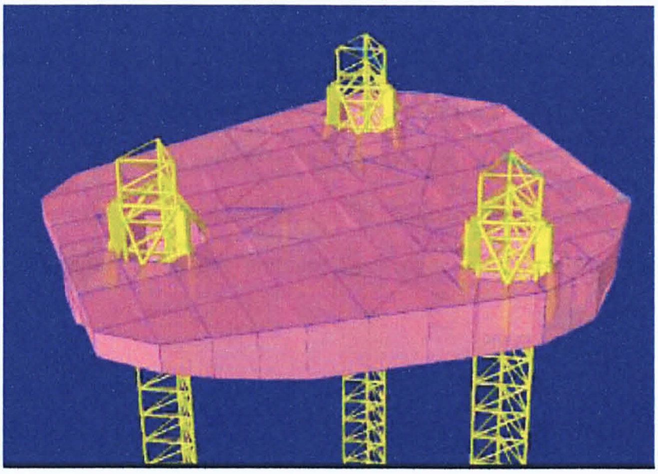


Figure 5. 5 SACS model of Jack-up structure

SACS is able to analyze the structure statically and dynamically. It has capability to calculate the joint displacements and element internal forces in static analysis mode. In dynamic analysis mode, it is able to perform deterministic and random dynamic wave response analysis, extreme wave analysis, ice vibration and impact analysis, dynamic Spectral extreme wind and wind fatigue analysis and base and force driven vibration analysis.

5.4 Performing Laboratory Tests on the Scaled Physical Model

The purpose of this stage was to verify the results of analysis by performing some experiments on the scaled physical model. At this stage, the scaled model of West Prospero Jack-up was constructed and tested at hydraulic laboratory of Universiti Technologi PETRONAS (UTP) under simplified conditions. The model was designed to be placed in the flume in the mentioned lab. This flume was the representation of Jerneh and Tapi fields in east coast of peninsular Malaysia. The following sections are provided to describe the features of UTP's hydraulic laboratory flume, explain the methods used to measure the wave properties, wind properties and deflection and also illustrate the strain gauge measurements generally.

5.4.1 Hydraulic Lab Flume

This section describes the features of UTP's hydraulic lab flume which includes modular flow channel, wave generator flap, switch box, hook and point gauge and pump.

5.4.1.1 Modular Flow Channel

Modular Flow Channel HM 162 (Figure 5.6) is an open flume providing experimentation possibilities for weirs, overflows, sluices, oceanography, and offshore engineering, etc.

Figure 5. 6 Modular flow channel

As it is shown in Figure 5.7, the flume is 12m long, 300 mm wide and 450 mm deep. The sides of flume are made of transparent hardened glass which is particularly resistant to scratching and abrasion, do not discolor and are easy to clean.

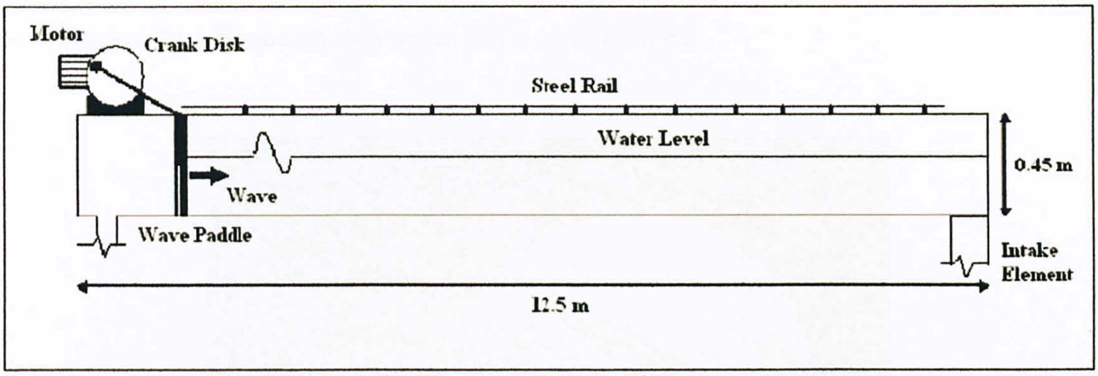


Figure 5. 7 Schematic drawing of the wave flume

5.4.1.2 Wave Generator Flap

The wave Generator HM 162.41 (Figure 5.8) is used to generate waves of various types in the flume. This unit helps to obtain information on the behavior of the waves in offshore areas and in coastal protection. The following properties are adjustable:

- Height(amplitude)
- Length(frequency)
- Velocity
- Shape

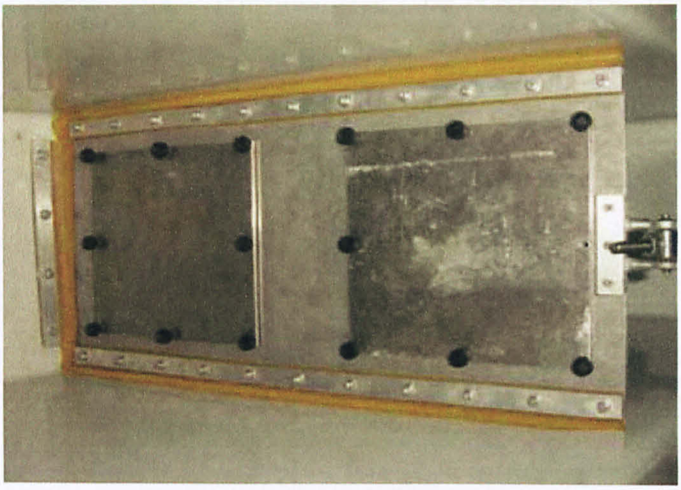


Figure 5. 8 Wave Generator

As it is shown in Figure 5.8, the wave generator is bolted onto the surrounding edge of the fume outlet. The wave generator is driven by a worm gear motor. The rotary movement of the motor is converted into harmonic stroke motion of the movable over-flow weir via a crank disk and a push rod connected to the overflow weir. See Figure 5.9. Rotational speed can be varied by a frequency converter and a potentiometer.

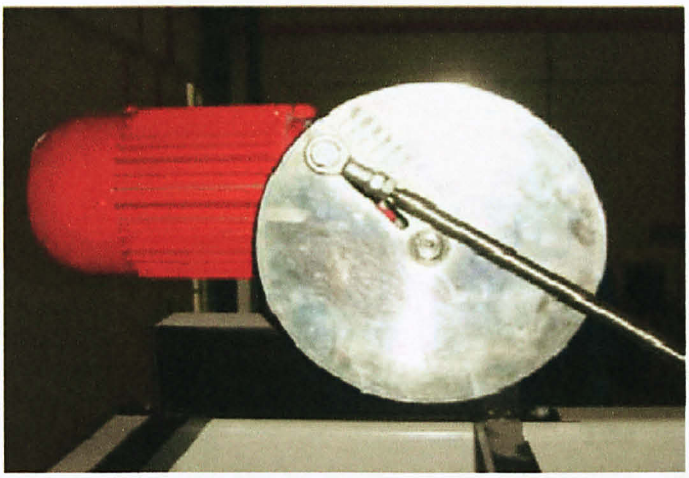


Figure 5.9 Motor, crank and push rod

5.4.1.3 Switch Box

All electrical switching units required for operations are located in the cover of a switch box (Figure 5.10). The rotational speed gives the stroke frequency of the wave generator and can be adjusted via a 10-gear helical potentiometer. The potentiometer has a scale disk for guaranteeing assignment of the rotational speed. At 100%, the rotational speed is 114 rpm, i.e. 1.9 Hz. The rotational speed varies linearly down to 0 rpm at 0%.

Figure 5.10 Switch box

5.4.1.4 Hook and Point Gauge

The hook and point gauge shown in Figure 5.11 is used to measure levels/water levels in the flume. It is possible to carry out measurements over the entire working range of the flow channel, since the measuring point can be traced in the longitudinal direction, across the width and in the depth of the flow cross section.

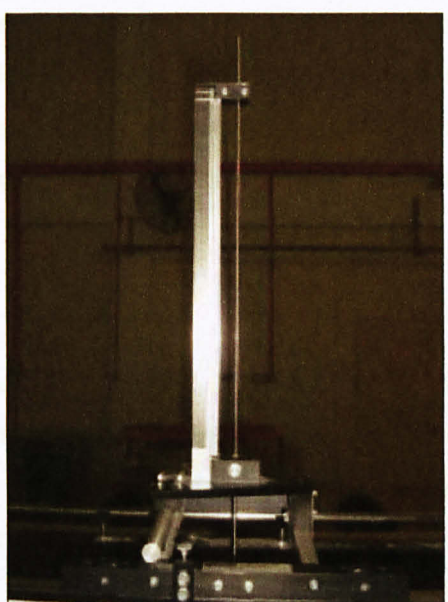


Figure 5. 11 Hook and Point gauge

5.4.1.5 Pump

The pump shown in Figure 5.12 consists of a base plate, a centrifugal pump and a flanged-on three-phase motor. On the motor there is a shut-off value with a lever on the suction side and a shut-off valve with gears and a hand-wheel on the pressure side. The flow rate is adjusted via the pressure-side shut-off valve during operation.

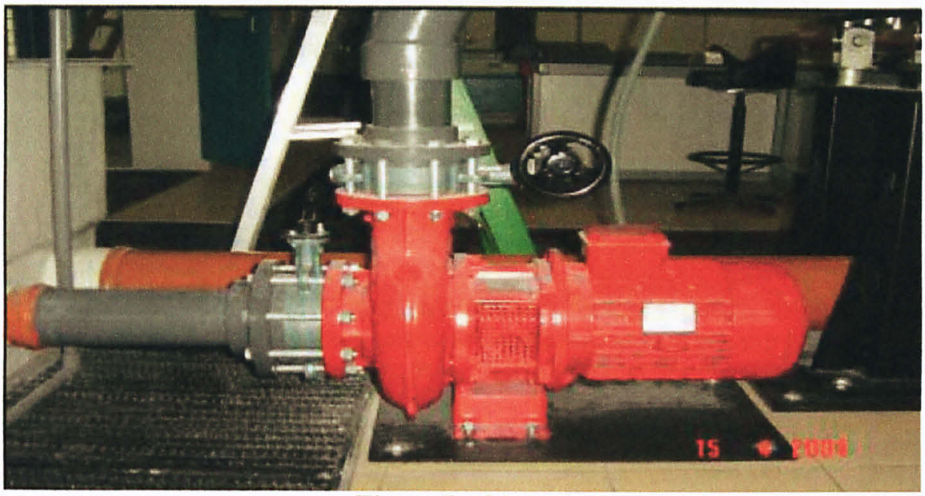


Figure 5. 12 Pump

5.4.2 Measurements

This section describes the methods used to measure the wave properties, wind velocity and deflection on the model placed in the flume during the experiments. The flume's wave generator flap was used to generate the waves. Wind was replicated using a conventional fan fixed over the flume near the model. Due to limitation of flume current could not be created.

5.4.2.1 Wave Properties

The height and period of waves generated in the flume are usually measured using wave probes. However, due to the absence of wave probes at UTP's hydraulic laboratory, these properties of waves were measured by visual observation. For this purpose, transparent graph paper was attached to the glass walls of the flume (Figure 5.13). A video camera was used to record the passing of waves. Reviewing the film allowed for measurement of the wave profiles over time.

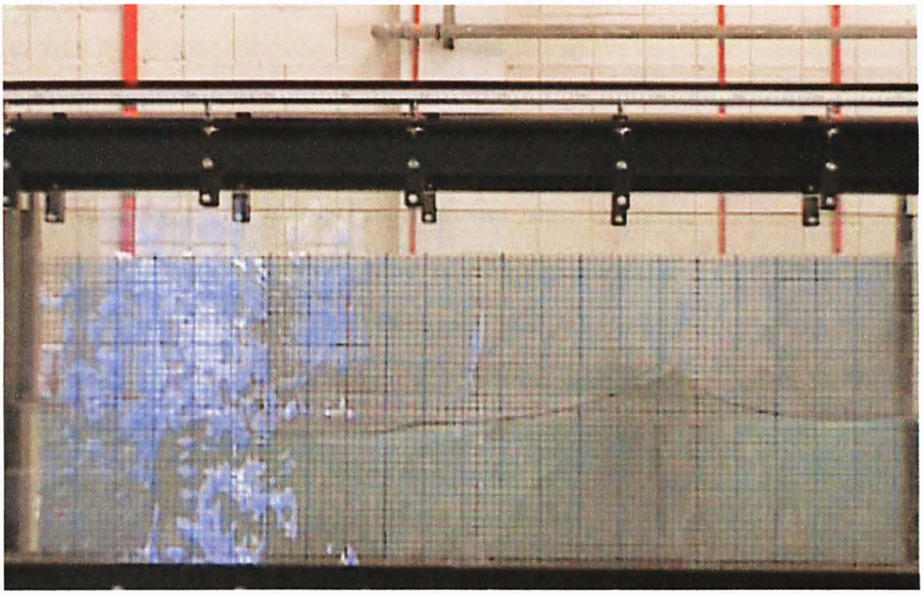


Figure 5. 13 Visual measurement using a transparent graph paper attached to the flume walls

5.4.2.2 Wind Velocity

Wind velocity generated by conventional fan was measured using flow meter. Figure 5.14 shows a photo of this equipment.

Figure 5.14 Flow meter

5.4.2.3 Deflection

Deflection was measured visually as it is explained in wave properties measurement.

5.4.2.4 Stresses

Strain gauges (Figure 5.15) can be used on the main members to measure strains. Later these strains will be translated into shear forces and bending moments. Strain gauges are designed to electrically detect the "strain", minute mechanical changes occurring in response to applied force. They enable detection of imperceptible elongation or shrinkage occurring in structures. Measurement of such elongation or shrinkage reveals the stress applied to structures.

Dynamic strain is strain whose magnitude changes quickly and sharply as when structures are subjected to vibration and impact. Such strain is usually measured with a strain amplifier.

Strain gauge is connected to KYOWA sensor interfaces PCD-30A series, which makes the existing PC a versatile measuring instrument. The PCD-30A enables the PC to perform force measurement through the use of strain gauge. The 265.2 x 215x 24.7-mm sensor interface has 4 measuring channels with maximum sampling frequency of 5 kHz. Once sensors are connected, interface operation on the PC enables measurement of strain data at a desired sampling rate. The control software PCD-30A enables the PC to control the sensor interfaces PCD-30A. Using the software, the PC sets measuring conditions and performs data acquisition, graph display and file conversion to CVS format on MS-windows 98/2000/XP (Figure 5.16).

It should be mentioned that due to the time limitation, this method could not be used and base shear was calculated by measuring deflation and reading forces from prepared calibration graph.

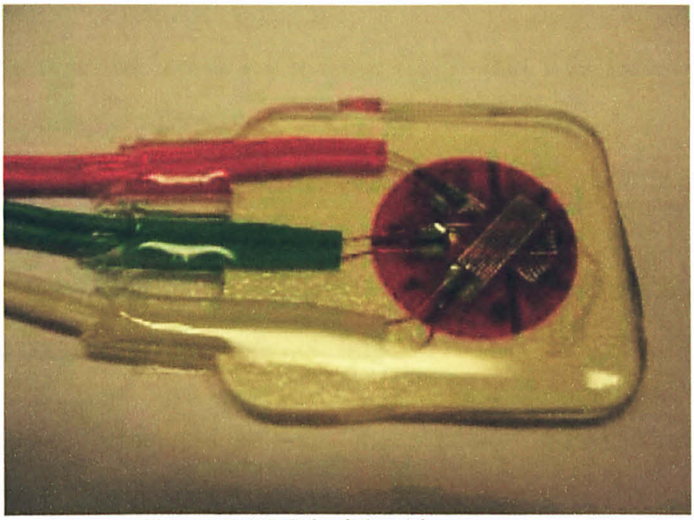


Figure 5. 15 Triaxial strain gauge

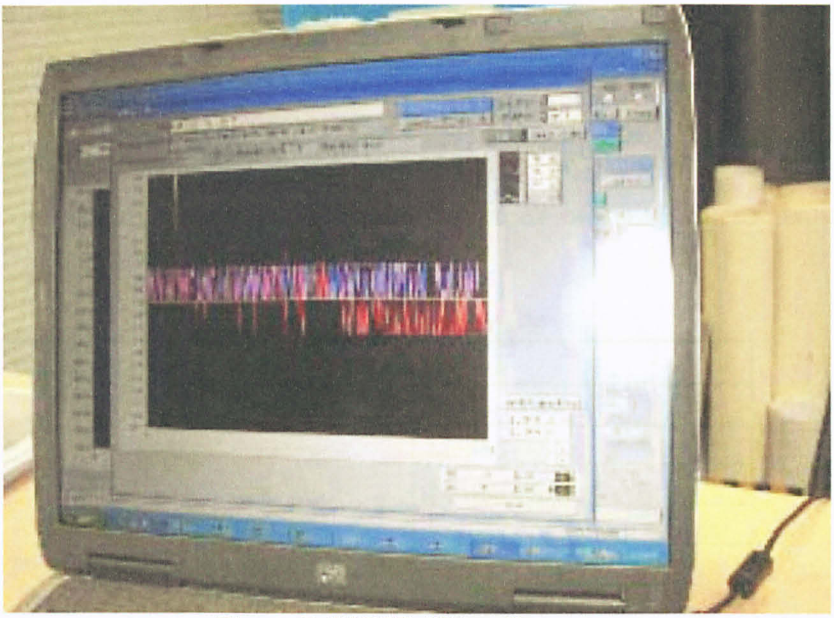


Figure 5. 16 PCD-30A software

5.5 Interpretation of Results

The last step in this project was to interpretate the data obtained from in-house software, SCAC software package analysis and experiments done in hydraulic laboratory and get the final conclusion on those results.

5.6 Health, safety and Environmental Aspects

Health, safety and environmental issues are a main factor that was focused on throughout this final project. The importance of this factor is:

- To prevent and eliminate the risk of injuries, health hazards and damage to properties.
- To identify steps towards the conservation and preservation of the environment.
- To minimize the unsafe act or unsafe conditioned

Accordingly by identifying the hazard sources, the particular form in which that hazard occurs, the areas of workplace or work process where it occurs and the persons exposed to that hazard, the writer strived to prevent the risk of injuries, protect the environment and accomplish the project successfully.

5.6.1 Hazard Sources

Hazard is a condition or combination of conditions that, if left uncorrected, may lead to an accident, illness, or property damage. The main sources of hazards are summarized in Table5.4.

Table 5.4 Sources of hazards

Type of Hazard	Source
Physical/Mechanical Hazard	Noise
	Motion
	Falling objects
	Rolling or pinching objects
	Poor lighting
	Electrical
	Extreme temperatures
	Fire and explosion
	harmful Dust
Chemical Hazard	gases
	Dust
	Fume
	Vapor
	Liquid
Biological Hazard	Infectious
	Bacteria
	Viruses

In order to identify the hazard sources in this project, the writer conducted walk-through surveys and consulted with her supervisor and technicians. The main identified potential hazards associated with this project are summarized in Table 5.5.

Table 5.5 Identified potential hazards associated with this project

Workplace	Type of hazard	Potential source of hazard
Manufacturing workshop	Physical	Cutting Process
		Falling objects
		Electrical
		Fire and explosion
		harmful Dust
		Noise
	Chemical	Liquid
		Dust
		Gas
	Biological	-
Hydraulic laboratory	Physical	Motion
		Falling objects
		Electrical
	Chemical	-
	Biological	-
Computer laboratory	Physical	Uncomfortable physical environment due to temperature, humidity, lighting, noise, vibration
		Uncomfortable furniture
		Poor posture
	Chemical	-
	Biological	-

5.6.2 Hazard Occurrence Situations and Methods of Prevention

As it is mentioned earlier, in this project, the hazards may occur in three main workplaces, which are manufacturing workshop, hydraulic laboratory and computer laboratory. The following sections describe the situations that may lead to accident in each workplace and the techniques to prevent them.

5.6.2.1. Manufacturing workshop

In order to build the scaled model of West Prospero jack-up to be used to perform the laboratory experiments, manufacturing workshop is used. The following are the potential hazards and the particular forms in which those hazards may occur at this workshop:

- Cutting: may occur during cutting process when the body parts are in contact with sharp edges.

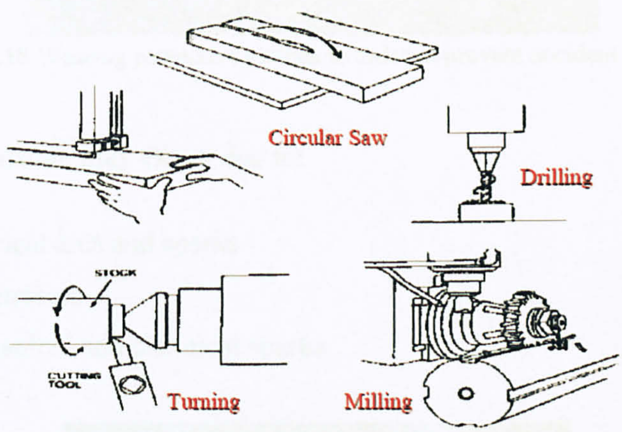


Figure 5.17 Cutting process may lead to accident

In order to minimize this type of hazard, the following safeguards should be considered:

- Wearing protective clothes and personal equipments
- Following standard operating procedures (SOP) implement safe work steps to check, set up machines, start, and finish job or task.
- Using padlock or tag to prevent a machine from being turned on until the lock is removed.

Figure 5.18 Wearing protective clothes in order to prevent accident during cutting process

- Fire and explosion: may Occur due to:
    - Electrical arcs and sparks
    - Hot surfaces
    - Mechanical and chemical sparks

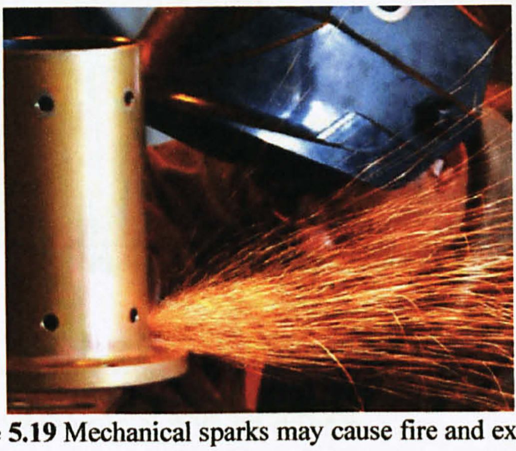


Figure 5.19 Mechanical sparks may cause fire and explosion

In order to reduce this type of hazard, the following safeguards should be considered:

- Wearing protective clothes and personal equipments
- Keeping the flammable substances such as wood and paint away from the machines produce sparks while operating(e.g. welding machine)

- Electrical shock: may occur while working with power tools. The severity of shock depends on the time duration and the current passes through the body.

  In order to prevent this type of hazard, the following safeguards should be considered:
  - Using three wire systems, consisting of live wire, natural wire and ground.(See Figure 5.20)
  - Not working with bare foot and shoes having nails while handling electrical equipments.
  - Ensuring that the electric power is disconnected from the appliance before attempting any adjustment work.

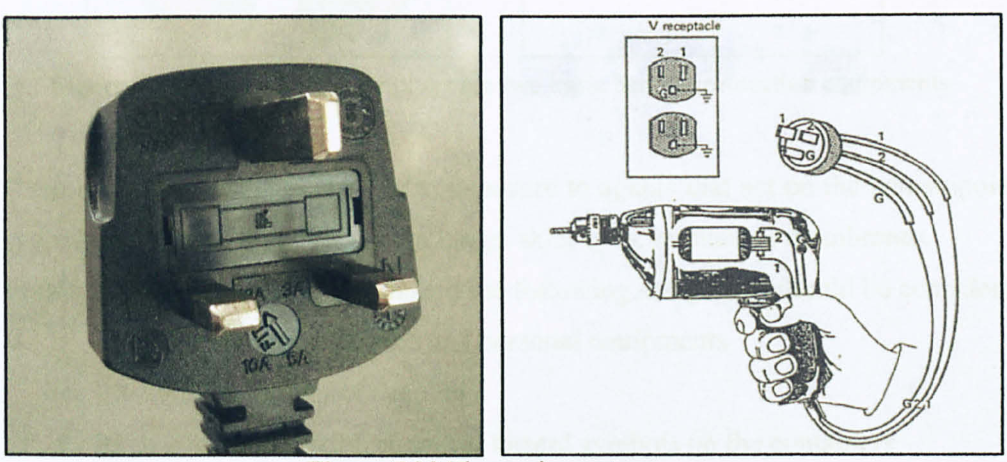


Figure 5.20 Three wire system

- Falling: may occur when there is:
  - A foreign object on the walking surface.
  - An uneven surfaces, poorly designed floor coverings
  - A slippery floor

The following precautions must be considered in order to prevent this type of hazard:

- Keeping the surface area clean and dry
- Wearing shoes with special non-skid soles
- Inspecting surfaces frequently

- Noise: is caused in part by the many potential sources of loud noise on laboratory such as drilling machine, cutting machine and etc. Prolonged exposure to excessive noise can cause permanent hearing losses unless noise control measures are taken.

  In order to prevent this type of hazard, one of the ways is to use personal protection equipment the two basic types of hearing protection are ear muffs and ear plugs.

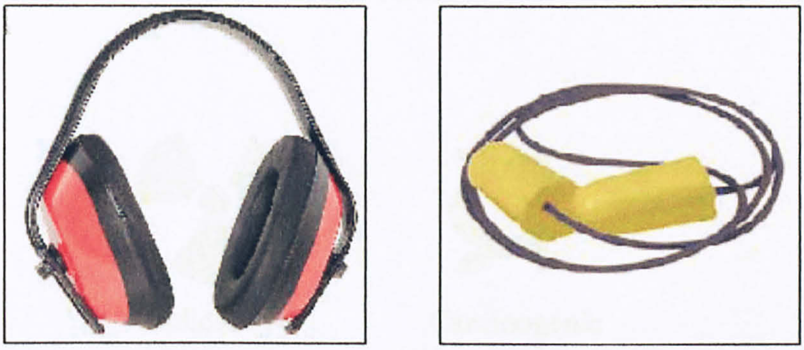


Figure 5.21 Ear muffs and ear plugs are two basic hearing protection equipments

- Chemical hazard: may occur due to exposure to agents that act on the hematopoietic system, and agents that damage the lungs, skin, eyes, or mucous membranes.
  In order to prevent this type of hazard the following safeguards should be considered:
  - Wearing protective clothes and personal equipments
  - Practicing good house keeping
  - Paying attention to the chemical hazard symbols on the containers

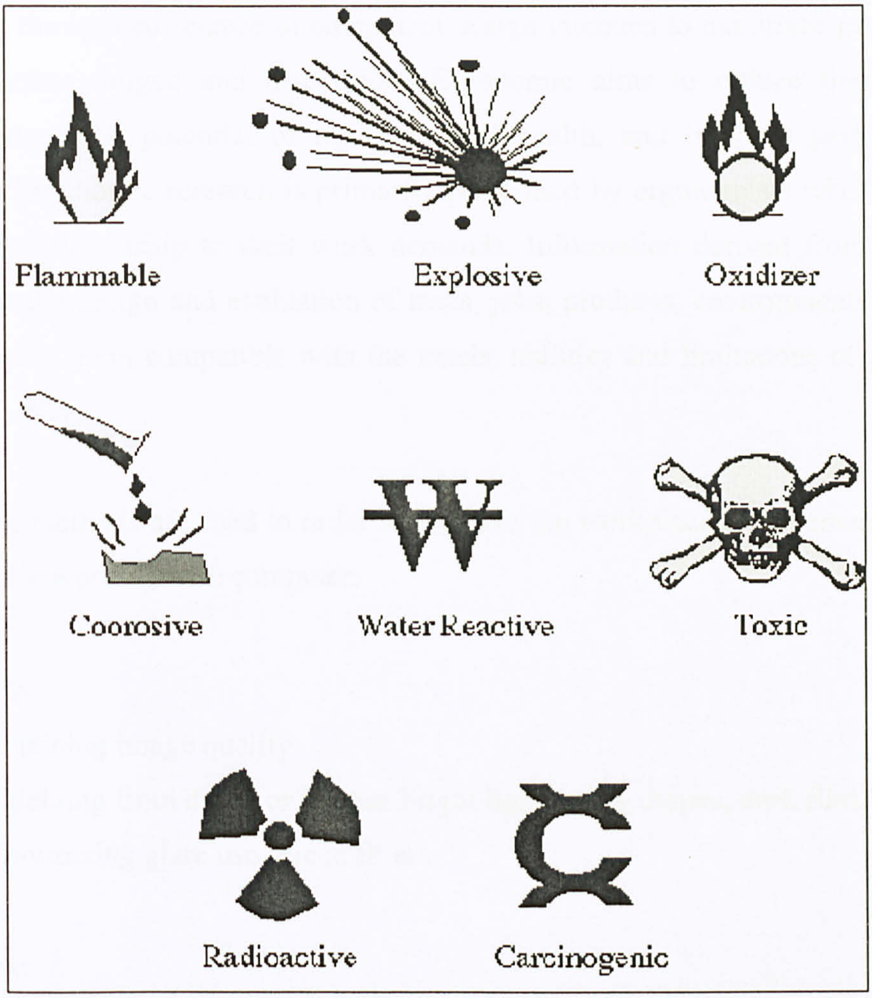


Figure 5.22 Chemical hazard symbols

5.6.2.2 Hydraulic laboratory

Hydraulic laboratory is used to carry out the experiments on built scaled model of West Prospero jack-up. The main hazards that may occur in this laboratory are falling, electrical shock and hazard due to motion. The particular forms in which those hazards may occur at this workshop is same as manufacturing work shop as described earlier.

5.6.2.3 Computer laboratory

Computer laboratory is used to perform the analysis on West Prospero jack-up using SACS software. Uncomfortable physical environment, poor posture of body, uncomfortable furniture and using computer for long period without any break (Static posture) may cause injuries, illness and therefore endangering health at this laboratory.

Ergonomic is the applied science of equipment design intended to maximize productivity by reducing operator fatigue and discomfort. Ergonomic aims to reduce the potential of accidents, reduce the potential of injury and ill health, and improve performance and productivity. Ergonomic research is primarily performed by ergonomists who study human capabilities in relationship to their work demands. Information derived from ergonomists contributes to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people (IEA, 2000).

The following methods are used in order to improve the workplace arrangement and protect the health while working with computer:

- Lighting
  - Retaining image quality
  - Shielding from direct or intense/bright light: using drapes, dark film, louvers.
  - Minimizing glare use screen filters

- Chairs:
  - Using a chair that is stable, mobile, swivels, and allows for operator movement.
  - Using a chair that provides substantial lower back support. The back support should be easy to adjust backward, forward, up, and down. A properly adjusted chair is important to help reduce or prevent discomfort on the back and should support the inward curve of the back.
  - Using a chair that has an adjustable seat height. Raise or lower the chair to a comfortable height such that the thighs are parallel to the floor and the knees are at a 90-degree angle. Rest the feet flat on the floor or use a footrest.
  - Using the armrests if they allow maintaining elbows at a 90-degree angle. If the armrests obstruct sitting posture, then adjust the armrests, use a chair that allows an erect posture, or use a chair without armrests.

- Work Surfaces:
  - Adjusting the work surface (table) so that the keyboard is at the correct height to maintain the best posture (elbows at keyboard height with the forearms parallel to the floor). If possible, use a split-level design table that has an adjustable top height: the lower level for the keyboard and mouse or trackball, and the upper level for the VDT monitor. The height of each level should adjust separately.
  - Using a table large enough to hold the keyboard, monitor, wrist rest, mouse or trackball, and a document holder or all necessary documents.
  - Keeping adequate clearance under the table for leg length, knee height, and thighs.

- VDT Monitors:
  - Positioning the VDT monitor directly in front and in line with the keyboard.
  - Positioning the VDT at a comfortable viewing distance (18-24 inches from the eyes), viewing height (top of the display screen at or slightly below eye level), and viewing angle (10-15 degrees below the horizontal line of sight).
  - Using a VDT monitor that tilts and rotates.
  - Using a VDT monitor that has adjustable contrast and brightness. Adjust the contrast to a high level and the brightness to a low level to minimize or prevent eyestrain.
  - Keeping the display screen or glare shield clean because dust reduces character clarity and reflects light.

- Keyboards:
  - Using a keyboard that is detached from the VDT monitor.
  - Positioning the keyboard directly in front of your torso.
  - Positioning the keyboard approximately at elbow height.
  - Adjusting the keyboard angle to a comfortable position; keep the wrists straight and in line with the forearm. The control to adjust the angle is located at the rear of the keyboard.

- Other Input Devices:
  - When using a mouse, trackball, or special keypads, placing the wrist in a neutral position. Rest the arm and hand close to the body and at the natural elevation. Do not reach forward, outward or raise the shoulders.
  - Using the whole arm to move the input device instead of just the wrist.
  - If the arm is resting on the table edge (hard work surface) when using the mouse or trackball, then using a mouse-pad rest to provide cushion.

- Wrist Rests/Pads:
  - Using a wrist rest for support to help maintain a neutral wrist position.
  - Using a wrist rest for cushioning to protect the wrist from resting on a hard or sharp work surface. Note that wrist rests are designed to be used during pauses in typing.

- Footrests:
  - Using a footrest that has an adjustable height and heel stop.
  - Using a footrest that is large enough to allow for movement.

- Printers:
  - Using a printer with a low noise level.
  - Locating the paper supply where it can be easily reached.

- Exercises:
  - For the eyes, looking away from the work to a distant point at least every hour.
  - For the body, stretching the neck, shoulders, back, legs, arms, and fingers at least twice a day. Standing up and walking around often to increase blood flow circulation.

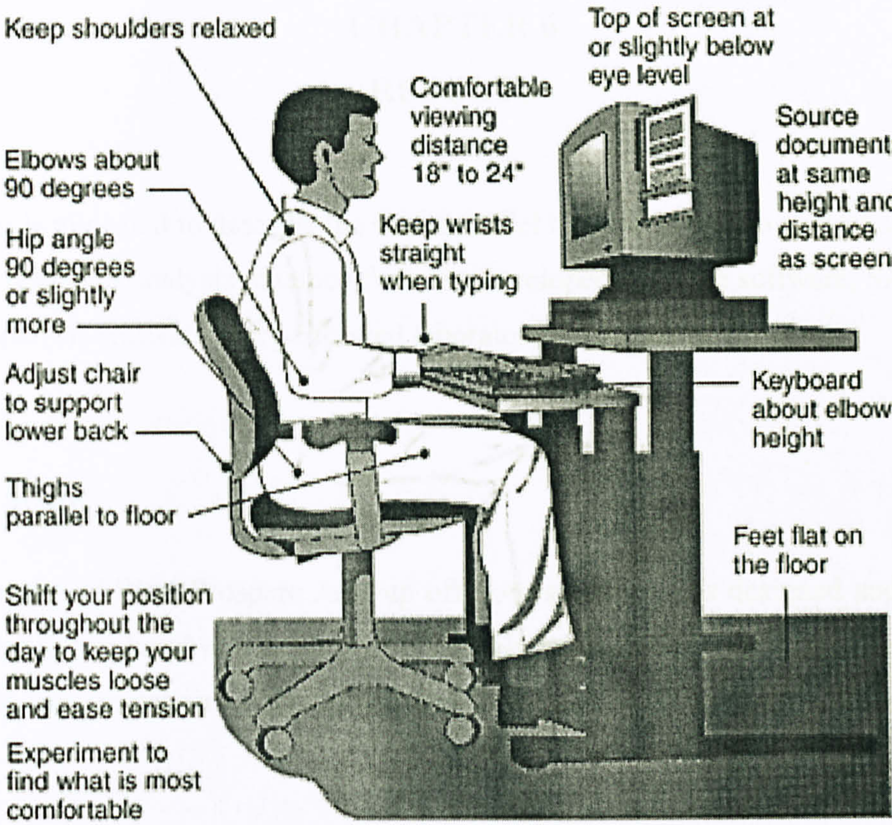


Figure 5.23 Preferred posture at a computer workstation

CHAPTER 6
RESULTS

This chapter is allocated to describe the scaled model of West Prospero as it was built and present the results of analysis obtained from the developed in-house software, SACS structural analysis software and performed laboratory experiments.

6.1 Scaled Model

A scaled model of West Prospero Jack-up offshore structure was designed and constructed by the author to be placed in the flume of UTP's Hydraulic laboratory. This flume is the one-dimensional representation of the Jerneh and Tapis fields off the east coast of peninsular Malaysia.

It should be mentioned that soil and foundation (i.e. spudcans) of the Jack-up were absent in the model and the model was fixed to the flume bed directly and firmly by using a heavy steel plate. The reason for absence of the soil and spudcans is that by placing the soil at the bottom of the flume to represent the seabed and including foundations in the tests, the limited height of the flume should be divided to soil and water and this causes scale down of the model a great deal which is not desirable. Consequently, the focus of this project was to quantify the inherent reliability of the Jack-up's substructures. The failure of the foundation was excluded from the study.

Further more, in this experimental study the deflection was measured visually. Knowing the fact that high rigidity reduces the flexibility of the structure and hence reduces the deflection, high rigidity is not desirable as it makes the deflection not to be identified visually. To solve the problem, the diagonal braces were excluded from the scaled model.

6.1.1 Scale

In order to have complete similarity between model and prototype, the geometric, kinematic and dynamic similarity must be maintained between the two systems [5]. The following sections described how the model of West Prospero Jack-up and environmental condition at Jerneh and tapis fields were scaled to maintain these similarities with its prototype.

6.1.1.1 Geometric Scale

Basically there were two constrains in scaling the model at UTP's hydraulic lab which were imposed by height and width of flume. In order for the water not to spill out of the flume, the total depth of water including the storm surge and wave height should be less than height of flume. Furthermore; in order for the model to fit inside the flume comfortably, the width of the model should be less than the width of flume.

As it is indicated in Table 5.2, at the location of the West Prospero Jack-up, the water depth including storm surge is 67.06 m and the maximum wave height is 16.46m. Therefore, the top of the splash zone is 67.06+16.46=83.5m above the seabed. Given that the height of hydraulic flume is 450mm, in order for the water not to spill out of the flume, the adopted scale should be smaller than

$$\lambda = \frac{0.45m}{83.5m} = \frac{1}{186}$$

Alternatively, as it is contained in Table 5.1, the width of hull is 71.3 m. Knowing that the width of model should be less than the width of the flume which is 300mm, the adopted scale should be smaller than

$$\lambda = \frac{0.3m}{71.3m} = \frac{1}{238}$$

Therefore, scale of 1:250 was chosen which complies both constrains.

6.1.1.2 Kinematic and Dynamic Scales

Table 6.1 contains the selected scales for the kinematic and dynamic environmental parameters of Jerneh and Tapis fields.

Table 6.1 Kinematic and dynamic scales

Wave period:	$\sqrt{\lambda} =$	$\frac{1}{16}$
Current speed:	$\sqrt{\lambda} =$	$\frac{1}{16}$
Wind speed:	$\sqrt{\lambda} =$	$\frac{1}{16}$

It should be mentioned that the model is a distorted model. Dynamic similitude is difficult to attain for an offshore platform that is partially submerged: it is affected by the wind forces in the air above it, by hydrodynamic forces within the water under it, and especially by wave motions at the interface between the water and air. The scaling requirements for each of these phenomena differ, so models can not replicate what happens to a full sized platform. Moreover, one must consider the limitations of the experimental facilities, materials and measurement equipment in the scaling down the various variables involved.

6.1.2 Dimensions

Table 6.2 contains the dimensions calculated for the scaled model of West Prospero Jack-up offshore structure.

Table 6.2 Dimensions of scaled model of West Prospero

Hull: 285mm × 253mm × 48mm
Overall leg length(excluding spudcans): 421mm
Diameter of chords: 3mm
Diameter of horizontal braces: 2mm
Length of horizontal braces: 20mm
Leg spacing: Traverse: 173 mm, Longitudenal:157 mm
Vertical spacing between the horizontal braces: 30mm

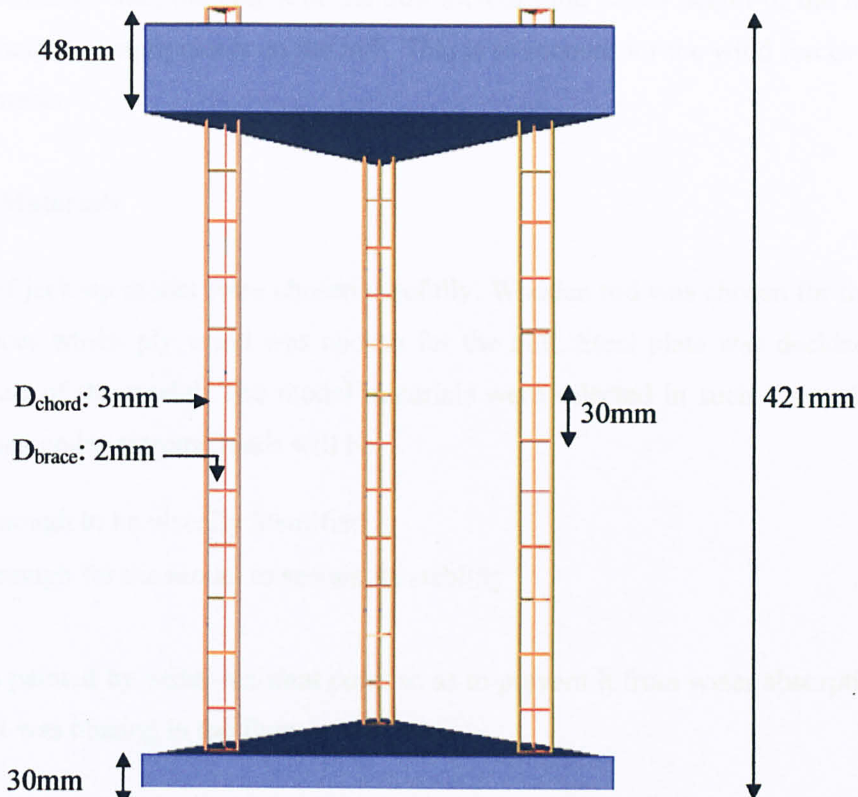


Figure 6.1 Model dimensions-Side view

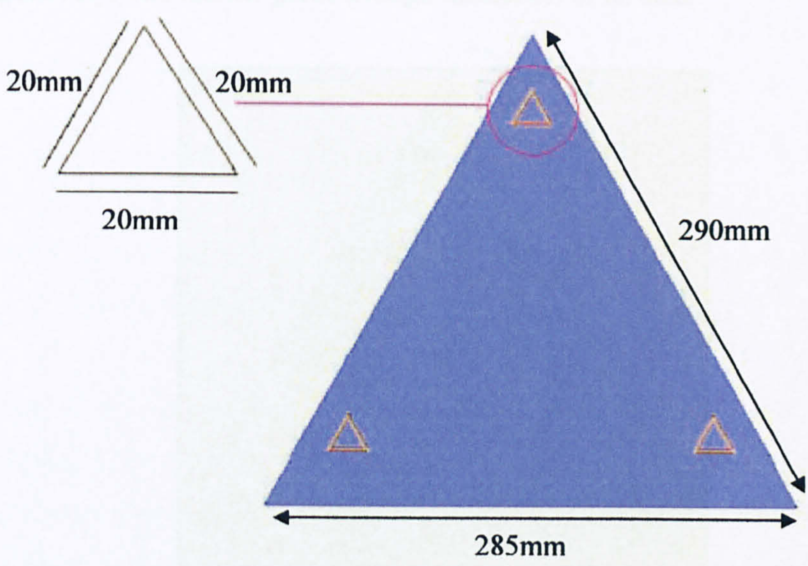


Figure 6.2 Model dimensions-Plan view

It should be mentioned that, the height of the hull includes the actual height of the hull and the average of height of equipments on the hull. This is to account for the wind forces caused by these equipments.

6.1.3 Selected Materials

The materials of jack-up model were chosen carefully. Wooden rod was chosen for the leg's chords and braces whilst ply wood was chosen for the hull. Steel plate was decided to be used for the base of the model. The model materials were selected in such a way that the model deflections under extreme loads will be:

- Large enough to be visually identified
- Small enough for the model to sustain its stability

The model was painted by water-resistant paint so as to prevent it from water absorption and damage while it was placing in the flume.

6.1.4 Final Product

Figure 6.3 and Figure 6.4 demonstrate the plan view and side view of the completed scaled model respectively. The marker gives a rough indication of its size.

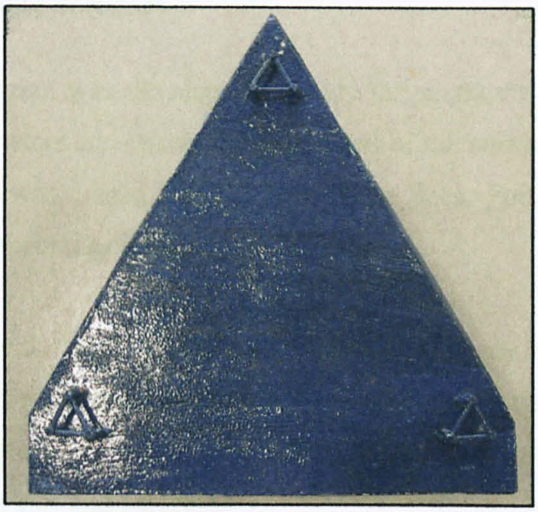


Figure 6.3 Plan view of built model

Figure 6.4 Side view of built model

6.2 Developed an In-house Software

A simple computer program was developed to study the sensitivity of Jack-up structure to the environmental parameters and ensure the soundness of the commercial software (SACS). The developed software was named BASFJOSEL (Base Shear Force of a Jack-up Offshore Structure under Environmental Loads).

This program allows for the preliminary stability analysis of any type of jack-up offshore structure (Triangular and rectangular hull, three Trussed leg, four trussed leg and cylindrical leg) by calculating the total shear force at the seabed (base shear) under major environmental loads including waves, winds and currents.

6.2.1 Algorithm

BASFJOSEL follows the following logical sequence:

1. Select type of jack-up: type of hull, type of leg.

2. Define geometry of jack-up: dimensions of hull, leg, braces and foundation

3. Input environmental parameters: water depth including storm surge, maximum wave height, period of wave, associated current speed at the surface and maximum wind speed at 10m above SWL.

4. Estimate marine growth thickness.

5. Estimate empirical parameters to be used in Morison's equation: drag coefficient, inertia coefficient and shape coefficient.

6. Compute wave characteristics: wave length, wave speed, maximum water particle velocity at SWL and maximum water particle acceleration at SWL.

7. Develop wind velocity profile.

8. Compute wind drag force on hull and dray parts of legs of the structure incorporating velocity changes with depth.

9. Develop current velocity profile.

10. Compute current drag force on the submerged part of lags incorporating velocity changes with depth.

11. Compute wave force on submerged members of legs.

12. Compute total shear base load.

13. Assess the sensitivity of the structural stability of Jack-up to the various environmental parameters within their acceptable range.

6.2.2 Formulas

The developed program employs the following formulas to compute base shear and its constituent environmental loads on jack-up offshore structure. It should be mentioned that these formulas are taken from fluid mechanics texts and offshore platform design standards ([1], [17])

$$\frac{V_h}{V_H} = (\frac{h}{H})^{\frac{1}{n}} \tag{6.1}$$

$$F_{Wind} = \frac{1}{2}\rho_{Air} C_S A U_{Wind}{}^2 \tag{6.2}$$

$$F_{Wave} = F_i + F_D \tag{6.3}$$

$$F_i = C_M \rho_{Water} g \frac{\pi D^2}{4} H K_i \tag{6.4}$$

$$F_D = \frac{1}{2} C_D \rho_{Water} g D H^2 K_D \tag{6.5}$$

$$K_i = \frac{1}{2}\tanh(\frac{2\pi d}{L}) \tag{6.6}$$

$$K_D = \frac{1}{4} n \tag{6.7}$$

$$n = \frac{C_g}{C} = \frac{1}{2}(1 + \frac{4\pi d / L}{\sinh[4\pi d / L]}) \tag{6.8}$$

$$L = \frac{gT^2}{2\pi}\sqrt{\tanh(\frac{4\pi^2 d}{T^2 g})} \tag{6.9}$$

$$
\begin{cases} C_D = 1.2 - \dfrac{(R_e - 2(10)^5}{6(10)^5} & \text{for } 2(10)^5 < R_e \text{ -} 5(10)^5 \\ C_D = 0.7 & \text{for } 5(10)^5 < R_e \end{cases} \tag{6.10}
$$

$$
\begin{cases} C_M = 2.5 - \dfrac{R_e}{5(10)^5} & \text{for } 2.52(10)^5 < R_e \text{ -} 5(10)^5 \\ C_M = 1.5 & \text{for } 5(10)^5 < R_e \end{cases} \tag{6.11}
$$

$$
\mathrm{Re} = \frac{u_0 D}{\upsilon} \tag{6.12}
$$

$$
\text{Base shear} = F_{\text{Wave}} + F_{\text{Wind}} + F_{\text{Current}} \tag{6.13}
$$

6.2.3 Assumptions

The following is the list of assumptions were made in developing BASFJOSEL:

- All wave kinematics formulas are based on Airy wave theory.
- The structure is assumed to be hydro-dynamically transparent and hence Morisson equation is used.
- The direction of wind is predefined and can not be changed by user. It is selected in such a way that it causes maximum impact on the structure.
- The leg members are assumed to be circular in cross section.
- For triangular hull, the hull is assumed to be isosceles.
- The average of height of equipments on the hull is added to the height of the hull so as to account for the wind forces caused by these equipments.
- The vertical spacing between horizontal members is assumed to be identical except for the last bottom one.

6.2.4 Input Data

The geometry of the scaled model of West Prospero Jack-up and the scaled environmental parameters at Jerneh and Tapis fields, as it was created at the flume of UTP's Hydraulic laboratory, were input into the program. Table 6.3 and Table 6.4 contain these input raw data.

The results obtained from BSSFJOSEL are compared with experimental results in the next chapter.

Table 6.3 Geometry of scaled model of West Prospero

Hull	Triangular- 0.285m x 0.253m x 0.048m
Leg	Triangular-3-chorded-Spased at 0.224m apart (Traverse:0.173m, Longitudenal:0.157m)
Chords (vertical members)	Overall height (excluding spudcans): 0.421m, Diameter: 0.003m, Leg penetration:0.104m
Horizontal members	Length: 0.020m, Diameter:0.002m
Diagonal members	Vertical height:0.03m, Diameter: 0.002m,
Spud can	Diameter:0.057m

Table 6.4 Scaled environmental conditions at Jerneh and Tapis fields

Water depth including storm surge	0.26 m
Maximum wave height	0.066 m
Period of the 100-year wave	0.84 sec
Associated current speed at the surface	0 m/sec
Maximum wind speed at 10m above SWL	4.400 m/sec

In addition, the geometry of MSL Jack-up model and the environmental parameters at Central North Sea were input into the program. Table 6.5 and Table 6.6 contain these input raw data. The results obtained from BASFJOSEL are compared with SACS outputs in the next chapter.

Table 6.5 Geometry of MSL model

Hull	Triangular- 80m x 72m x 16m
Leg	Triangular-3-chorded-Spased at 55.01m apart (Traverse: 38.9m, Longitudinal: 38.9m)
Chords (vertical members)	Overall height: 146m, Diameter: 0.85m, Leg penetration:23m
Horizontal members	Length: 12.2m, Diameter:0.6m
Diagonal members	Vertical height: 6.96m, Diameter: 0.6m,
Spud can	Diameter: 14.33m

Table 6.6 North Sea environmental Parameters

Water depth including storm surge	96.6 m
Maximum wave height	31.2m
Period of the 100-year wave	17.7 sec
Associated current speed at the surface	0.67 m/sec
Maximum wind speed at 10m above SWL	40.1 m/sec

6.2.4 Output

Appendix B and Appendix C contain the output of the program for the West Prospero and MSL model respectively.

6.3 Simulated Response of the Jack-up Structure Using SACS

In order to assess the sensitivity of structural stability of Jack-up to the various parameters, the response of MSL model was simulated using SACS software. The formulas used by SACS to compute the environmental loads, the SACS input data and the associated output are presented in the following sections.

6.3.1 Formulas

SACS compute the resultant force distribution on the members due to fluid particle motion using Morison's equation. This is in accordance with API recommendation and produces reliable results for the members whose cross sectional dimensions are small with respect to both wave length and the characteristic distance between members.

SACS combined the resultant forces due to fluid particle motion and expressed in the member local coordinates:

$$\overline{F}_x = \frac{1}{2}\pi C_{Dt} D\rho\left|\overline{V}_t\right|\overline{V}_t \tag{6.1}$$

$$\overline{F}_y = \frac{1}{2}\pi C_{Dn} D\rho\left|\overline{V}_n\right|\overline{V}_y + \frac{1}{4}\pi C_{Mn} D^2 \rho\dot{\overline{V}}_y \tag{6.2}$$

$$\overline{F}_z = \frac{1}{2}\pi C_{Dn} D\rho\left|\overline{V}_n\right|\overline{V}_z + \frac{1}{4}\pi C_{Mn} D^2 \rho\dot{\overline{V}}_z \tag{6.3}$$

Where x, y and z are the member local coordinates, C_{Dn} is the drag coefficient for flow normal to the member, C_{Mn} is the inertia coefficient for flow normal to the member, D is the member diameter, ρ is fluid mass density, V_n is fluid particle relative velocity normal component and the subscript t refers to the member tangential (axial) direction.

For non-cylindrical members these equations are modifies to account for the fact that the member may have different hydrodynamic behavior in the local Y and Z direction. The equations for the components of force in the member local coordination are:

$$\overline{F}_x = \frac{1}{4}\pi C_{Dt}(D_y + D_{z)} D\rho\left|\overline{V}_t\right|\overline{V}_t \tag{6.4}$$

$$\overline{F}_y = \frac{1}{2}\pi C_{Dy} D_y\rho\left|\overline{V}_n\right|\overline{V}_y + \frac{1}{4}\pi C_{My} D_y{}^2 \rho\dot{\overline{V}}_y \tag{6.5}$$

$$\overline{F}_z = \frac{1}{2}\pi C_{Dz} D_z\rho\left|\overline{V}_n\right|\overline{V}_z + \frac{1}{4}\pi C_{Mz} D_z{}^2 \rho\dot{\overline{V}}_z \tag{6.4}$$

Where C_{Dy} and C_{Dz} are the drag coefficients for the flow in the local y and z directions and D_y and D_z are the effective member depth for flow in local y and z directions.

Wind load is generated on all members above the water surface as well as and wind areas designated. SACS calculate the pressure on members using the following equation:

$$P = 0.0338 V^2 C_h C_s \tag{6.5}$$

Where P is pressure (lb/sq.ft), V is velocity (knots), C_h is height coefficient and C_s is shape coefficient. C_s is taken as 0.5 for tubular member and 1.5 for other members. The wind force on the members and surface is normal to member and is calculated using the following equation:

$$F = PASin\alpha \tag{6.6}$$

Where A is projected area of the surface or member normal to the force and α is angle between the direction of the wind and te axis of the member.

6.3.2 Input

The SACS input file for MSL model was generated by modeling the Jack-up structure and environmental loads in Central North Sea in a 3D interactive environment. The environmental loads and their related cases were created as it is described bellow:

- Wave load was generated within the 8 different load cases as it was assumed that there are 8 possible wave approach directions. Wave theory, wave height and approach direction were specified for each load case.

- Current load was defined in conjunction with wave force and hence 8 different load cases were generated. For a particular load case, current velocities were input at different elevations from the mud line to the mean water surface.

- Wind load was generated within a load case. It was specified in one direction (180^O) and it was varied with height according to API recommendations.

- Operational load was generated by combining the effect of the wave, wind, current form same approach direction and dead load of the structure at normal operating condition. Consequently 8 different operational load cases were generated.

- Storm load was generated by combining the effect of the wave, wind, current form same approach direction and dead load of the structure at extreme environmental condition and so 8 different storm load cases were generated.

It should be mentioned that the environmental parameters related to each environmental load were as in Table 6.6. In addition, in any wave load case, the airy wave theory was selected as preferred theory.

Figure 6.5 shows the MSL model structure as it was defined in the input file. The seastate input data were summarized in the first part of Appendix D which is the SACS output file.

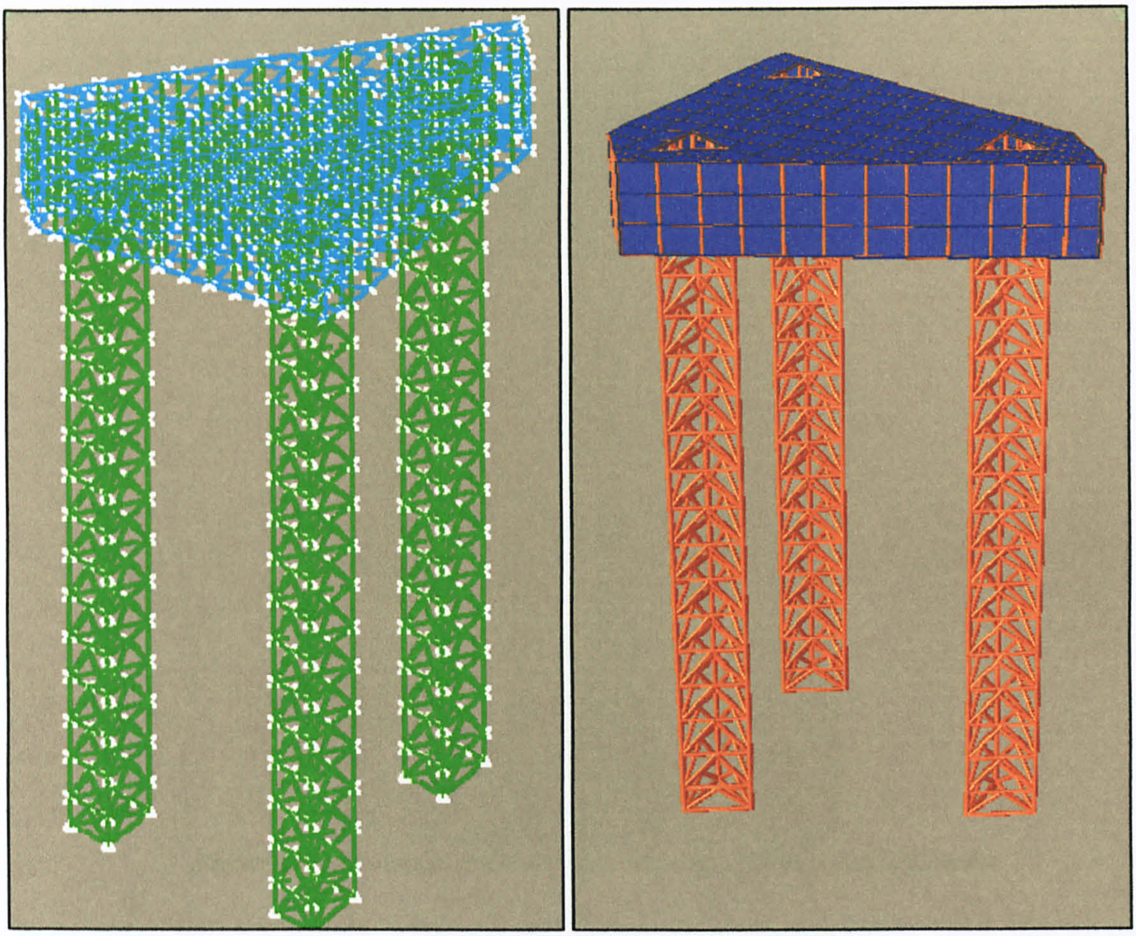


Figure 6.5 MSL model view

6.3.3 Output

The SACS outputs including the force and moment in X, Y and Z directions for the basic and combined load cases are summarized in Appendix D.

Since in BASFJOSEL, the approach direction of wind, wave and current is fixed and assumed to be in angle of 180 degree for Jack-up with triangular hull and three trussed legs, and also because one of the objectives of this project is to compare the results from SACS with BASFJOSEL, among all SACS results only the loads in X direction and associated with wind, wave and current with the approach angle of 180 degree were selected to be used in this study (i.e load label 2 and load label 44). In addition only overturning moment in Y direction is the concern of this project.

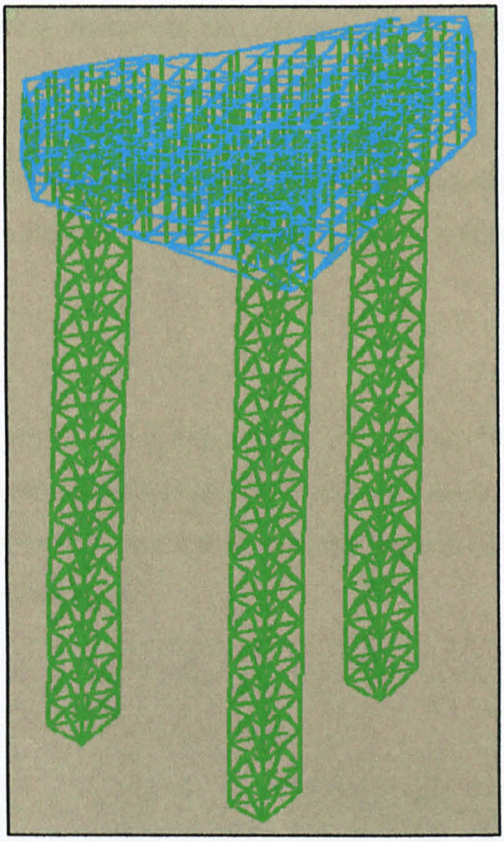


Figure 6.6 MSL model deflected under the applied environmental loads

6.4 Performed Physical Modeling Test

In order to evaluate the structural stability of the scaled model of West Prospero and verify the results obtained from in-house software, simple laboratory experiments were done on this scaled model at UTP's Hydraulic laboratory.

6.4.1 Calibration

In general "Calibration" refers to the process of determining the relation between the output (or response) of a measuring instrument and the value of the input quantity or attribute, a measurement standard.

In this study, prior to perform the experiments on the scaled model, calibration was done to determine the relationship between deflection of the model and magnitude and location of the applied loads.

6.4.1.1 Setup

In UTP's flume, waves, winds and currents exert entirely horizontal forces on the scaled model. Hence, a simple method to simulate these horizontal forces is by using pulley system. As it is shown in Figure 6.7 and Figure 6.8, this system includes: legs, clamps, wooden plate, pulleys, stings, hangers and weights.

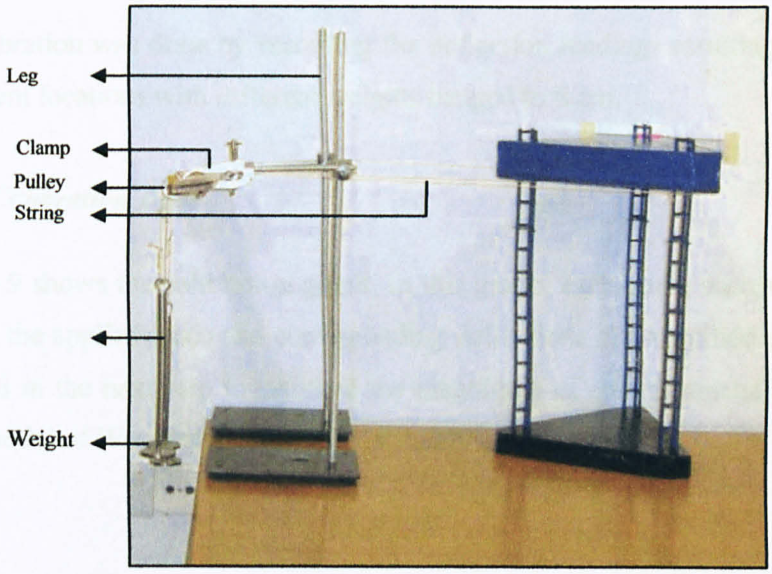


Figure 6.7 Side view of pulley system used for calibration

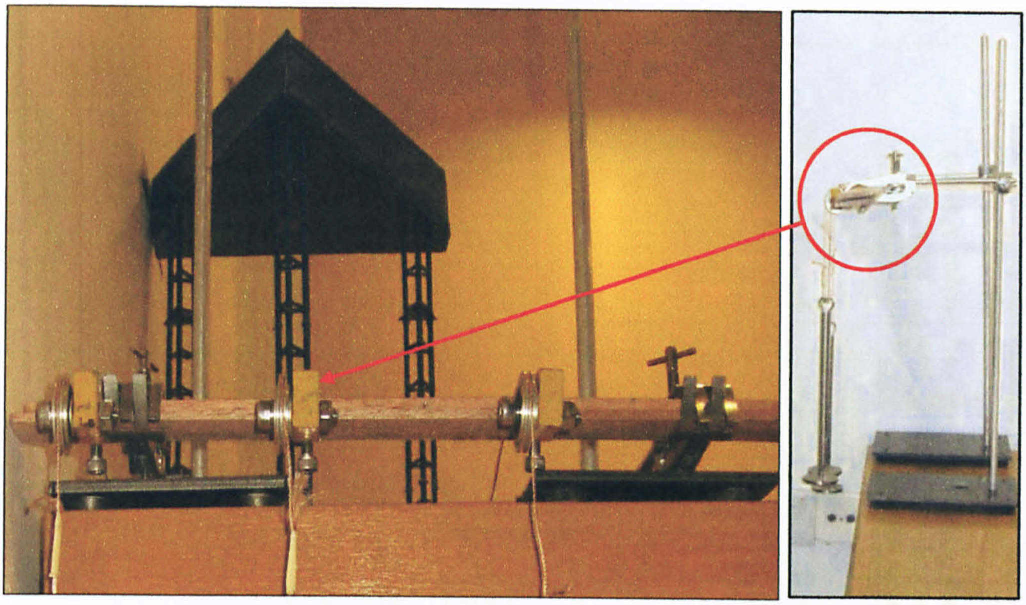


Figure 6.8 Front view of pulley system used for calibration

In this study, three pulley systems (i.e. one pulley system for each leg of the Jack-up model) were used to ensure that the loads applied on legs are identical. These pulleys were supported on a wooden plate which was in turn supported by two clamps and legs. Each string was fixed to a leg in one end and crossed over the pulley and tied to a hanger with the weights in another end. It should be mentioned that, the deflection of the scaled model is measured visually at the top of it.

The calibration was done by recording the deflection readings resulting from placing stings at different locations with different weights hanged to them.

6.4.1.2 Calibration Data

Figure 6.9 shows the calibration graph. In this graph, each curve represents the relationship between the applied loads and corresponding deflections at a specified elevation. This graph was used in the next step to estimate the magnitude of environmental loads applied on the scaled model of West prospero at UTP's flume.

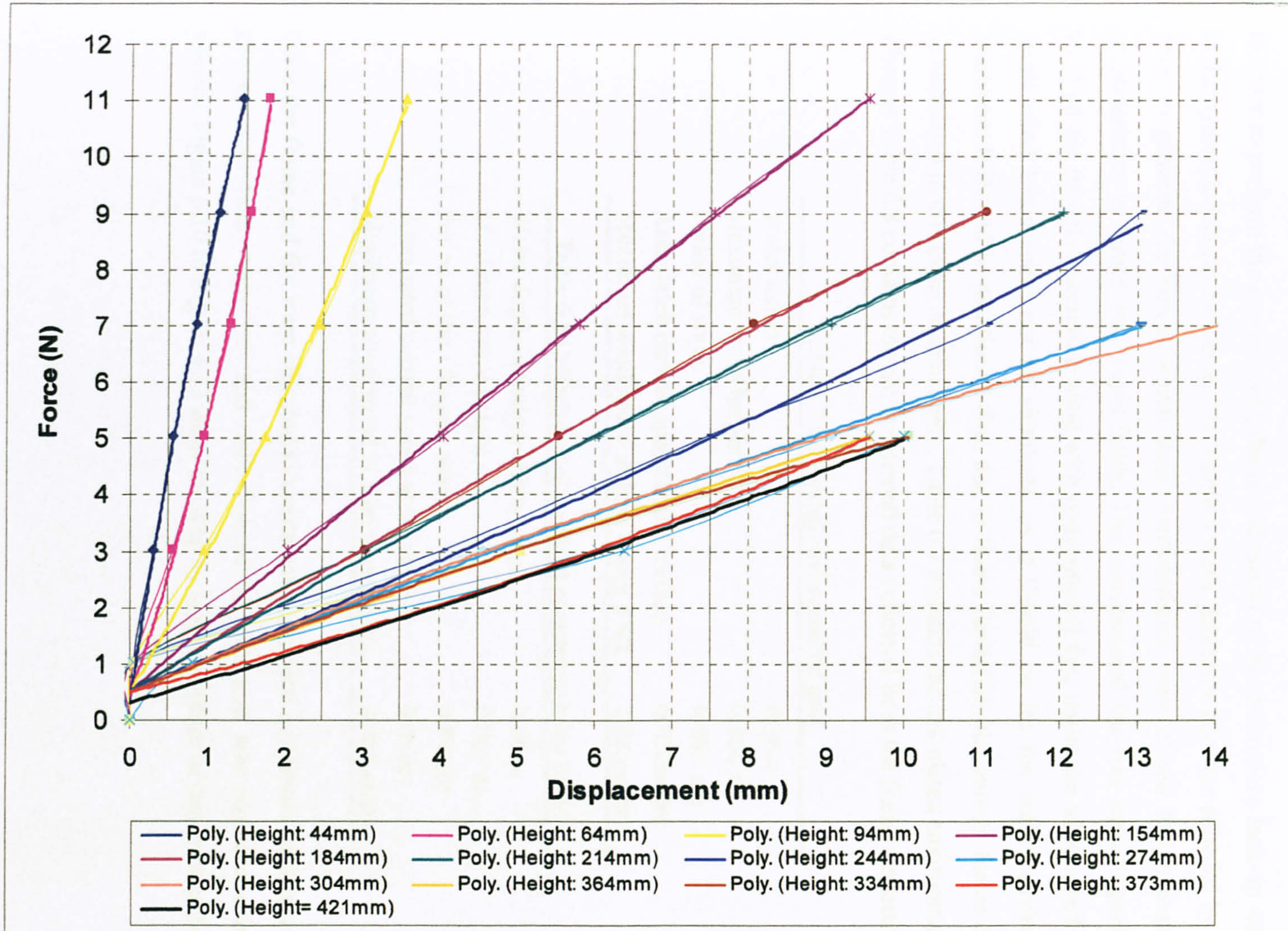


Figure 6.9 Calibration graph

6.4.2 Laboratory Experiments

In order to perform the experiments, the scaled model of West Prospero Jack-up was placed in the hydraulic laboratory flume. The flume's wave generator flap was adjusted by trail and error to generate the waves which their characteristics were closed to the scaled wave characteristics at Jerneh and Tapis fields. The conventional fan was used to generate the wind on the model. Generating wind with conventional fan, limits the wind speed and as a result wind loads could not be simulated as it should be for the scaled environmental condition. It should be mentioned that, due to flume limitation, the current forces could not be simulated in this experimental study. Table 6.7 contains the calculated environmental data whereas Table 6.8 contains the environmental data collected from the flume respectively.

Table 6.7 Calculated environmental data.

Water depth	0.26 m
Maximum wave height	0.066 m
Period of wave	0.885 sec
Associated current speed at the surface	0.032m/sec
Maximum wind speed at 10m above SWL	2.28 m/sec

Table 6.8 Collected environmental parameters in the flume

Water depth including storm surge	0.26 m
Maximum wave height	0.066 m
Period of the 100-year wave	0.84 sec
Associated current speed at the surface	0 m/sec
Maximum wind speed at 10m above SWL	4.400 m/sec

Once the flume and fan were adjusted to create environmental conditions as it is mentioned above, experiments were run and deflection of the structure was recorded using video camera. Figure 6.10 to Figure 6.13 show the step by step procedure of performing the tests.

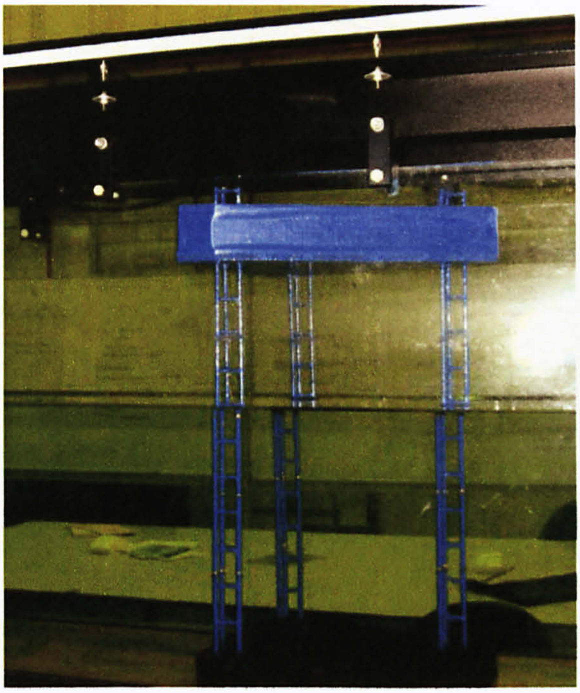


Figure 6.10 Scaled model of West Prospero was placed in UTP's flume and water depth was adjusted to 260mm.

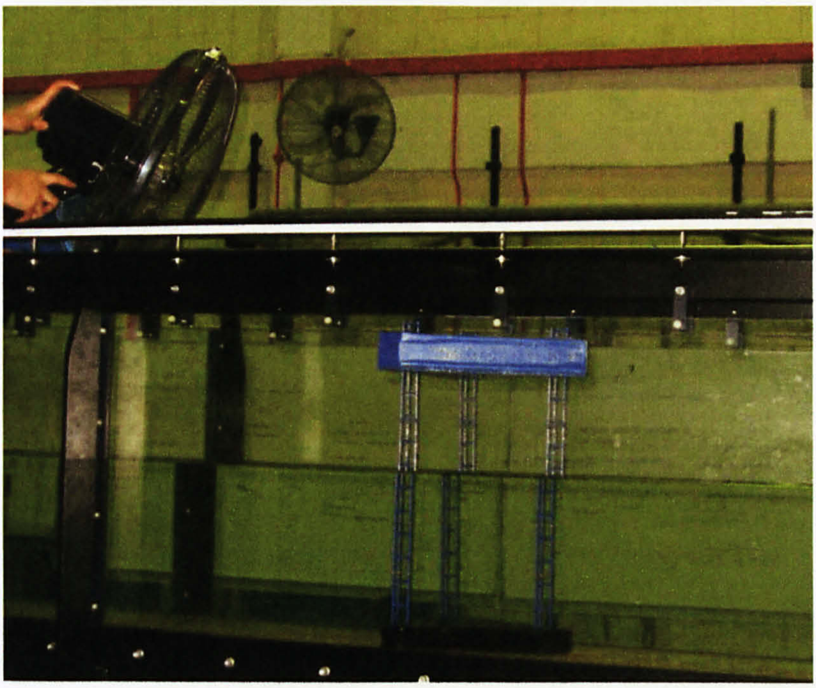


Figure 6.11 Fan was fixed over the flume

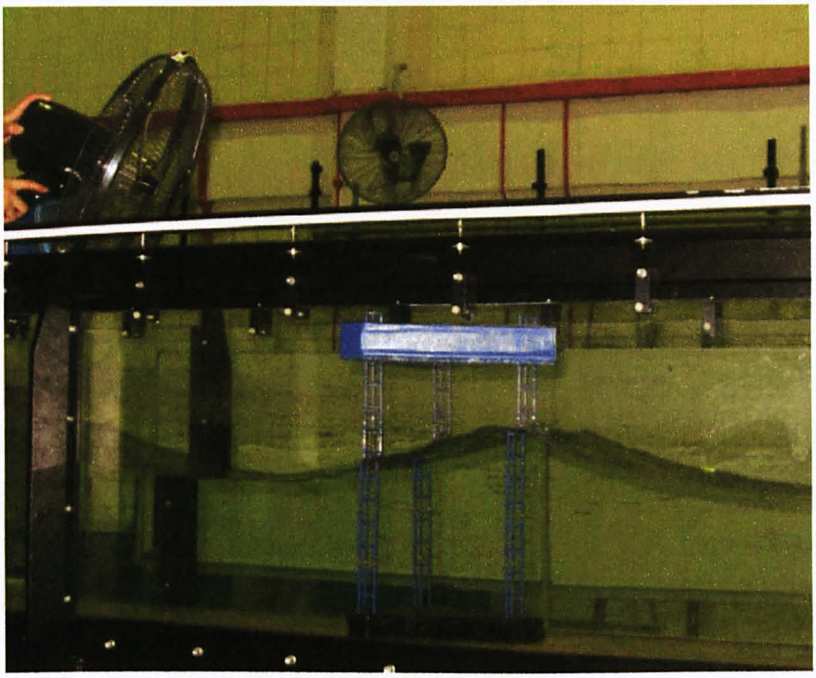


Figure 6.12 Waves and wind were generated in the flume

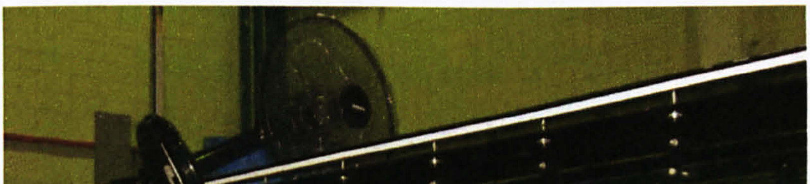


Figure 6.13 Deflection was recorded using camera

By reviewing the film, the deflection of the model under the generated wave and wind loads was obtained.

In order to use the calibration graph to estimate the base shear force, the location of the resultant forces (Wind and wave forces) must be anticipated primary. The location of each of the forces and the resultant force is estimated as follows:

- Since the wind force is positively proportional to squared wind speed and wind speed is in turn positively proportional to the height of the structure above the water with the power of (1/8), therefore the wind force is positively proportional to the height of the structure above the water level with the power of (1/4).Therefore the location of the wind force on the hull is at

  $$y_c = \frac{n+1}{4n+2}h \quad \text{h= height of the spandrel curve}$$

  $$y_c = \frac{\frac{1}{4}+1}{4\times\frac{1}{4}+2}\times 48mm = 20mm \quad \text{from the bottom of the hull}$$

  In the same manner, the resultant of the wind force on the chords and horizontal braces is located at:

  $$y_c = \frac{\frac{1}{4}+1}{4\times\frac{1}{4}+2}\times 113mm = 47mm \quad \text{from the sea level}$$

  Therefore the resultant wind forces act on the hull and dries parts of the legs is located somewhere between (47+260=307mm) and (20+113+260=393mm) from the mud line. By knowing the fact that the wind force act on the hull is lager than the wind force act on the dried part of the legs, the value of 370mm which is more than the averaged value was selected as the approximate location of the resultant wind forces from the mudline.

- Since the drag force is positively proportional to the squared water particle velocity and the water particle velocity is assumed to have the reverse relationship with the Z, hence the location of the resultant drag forces on the submerged parts of the structure is approximately at:

$$y_c = \frac{3}{4}h = \frac{3}{4} \times 260mm = 195mm \quad \text{from the mudline}$$

- Since inertia force is linearly proportional to the water particle acceleration and water particle acceleration is linearly proportional to the Z, hence the location of the resultant inertia forces on the submerged parts of the structure is located about:

$$y_c = \frac{d}{2} = \frac{260mm}{2} = 130mm \quad \text{from the mudline}$$

- Based on above calculations, the resultant forces of wave forces on the submerged parts of the structure should be somewhere between 130mm and 195mm. By knowing the fact that the drag force is larger that the inertia force in most of the cases, the value of 180mm which is more than the averaged value was selected as the approximate location of the resultant wave force from the mudline.

- In conclusion the resultant of the wave and wind forces act on the structure should be between the 180mm and 370mm. The value of 320 was selected as the approximate location of the resultant environmental forces on the model. This selection is due to the fact that the wind forces are the dominant among all environmental loads act on the model in this case. (Refer to section 8.1.1 of chapter 8 for more details).

After anticipation of the location of the resultant forces, calibration graph was referred to estimate the loads based on the recorded deflection. Table 6.8 contains these experimental results.

Table 6.8 Experimental Results

Force	Displacement (mm)	Shear force (N)
Wave + Wind	0.2	0.60

CHAPTER 7
DISCUSSIONS-PART I

This chapter is allocated to make use of BASFJOSEL output for MSL model in discussing the breakdown of base shear and its sensitivity to various parameters at first part, and then employing SACS output for the same model to discuss the breakdown of overturning moment and its sensitivity to various parameters in second and at last compare the SACS output for MSL model with BASFJOSEL output.

7.1 Breakdown of Base Shear

This section discusses the role of structural members as well as each environmental loads and its constituents in creating base shear in the Jack-up structure.

7.1.1 Breakdown of Base Shear by Environmental loads

Figure 7.1 shows the breakdown of base shear by major environmental loads which are wave, wind and current. It can be observed that the main portion of the base shear is created by wave loads. Therefore, wave loads play a major role in determining the reaction of the base shear to the changes in various environmental parameters.

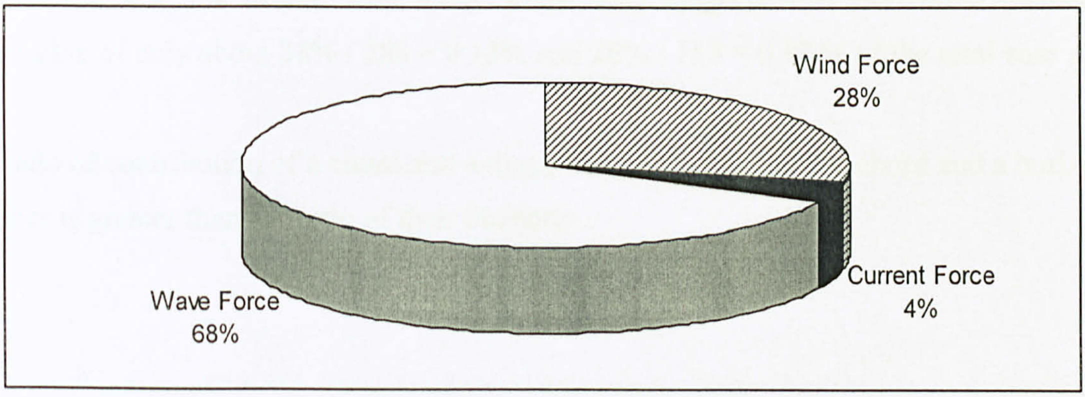


Figure 7.1 Breakdown of base shear by environmental loads

7.1.2 Breakdown of Base Shear by Structural Members

Figure 7.2 shows the breakdown of base shear by structural members. It can be seen that diagonal braces attract most of the environmental forces. The attraction of the environmental loads by the vertical braces is the least among all structural members. Lastly Hull of the Jack-up attracts a considerable amount of environmental loads in the form of wind loads.

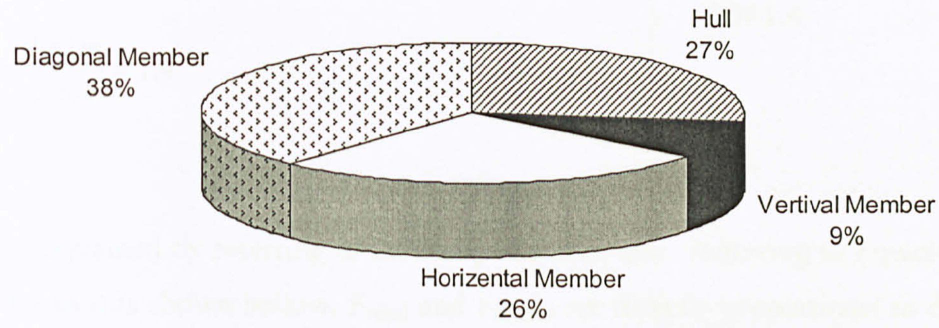


Figure 7.2 Breakdown of base shear by structural members

It should be pointed out that although diagonal members as a whole attract more environmental loads than the vertical members (chords), but the share of each diagonal member in environmental loads attraction is less than the vertical loads. In this case study, the number of vertical members is 9 whilst the number of diagonal members and horizontal members are 288 and 153 respectively. Therefore each vertical member is responsible for about 9% / 9 = 1% of the base shear while each diagonal and horizontal member is responsible of only about 38% / 288 = 0.13% and 26% / 153 = 0.17 % of the total base shear.

The ratio of contribution of a chord and a diagonal member and also a chord and a horizontal member is greater than the ratio of their diameter.

$$\left.\begin{array}{l}\dfrac{Contribution \cdot of \cdot chord}{Contribution \cdot of \cdot diagonal \cdot member} = \dfrac{1\%}{0.13\%} = 7.7 \\ \\ \dfrac{d_{chord}}{d_{diagonal}} = \dfrac{0.85m}{0.6m} = 1.4\end{array}\right\} 7.7>1.4$$

$$\left.\begin{array}{l}\dfrac{Contribution \cdot of \cdot chord}{Contribution \cdot of \cdot horizental \cdot member} = \dfrac{1\%}{0.17\%} = 5.9 \\ \\ \dfrac{d_{chord}}{d_{horizental}} = \dfrac{0.85m}{0.6m} = 1.4\end{array}\right\} 5.9>1.4$$

This can be explained by referring to the analytical formulas. Referring to Equation 4.1 and Equation 4.4 as it is shown bellow, F_{wind} and $F_{current}$ are directly proportional to diameter of the member through frontal area.

$$F_{Wind} = \frac{1}{2}\rho_{Air}C_S A U_{Wind}{}^2 \qquad F_{Current} = \frac{1}{2}\rho_{Water}C_D A U_{Current}{}^2$$

Similarly, referring to Equation 4.8b and as it is shown bellow; F_D in the wave force has linear relationship with diameter of the member.

$$F_D = \frac{1}{2}C_D\rho_{Water}gDH^2K_D$$

However, referring to the same equation and as it is shown bellow; F_i is proportional to the diameter squared. Therefore, as a whole, the ratio of base shear produced by the chord to a diagonal member and chord to a horizontal member is greater than the ratio of their diameters.

$$F_i = C_M\rho_{Water}g\frac{\pi D^2}{4}HK_i$$

7.1.3 Breakdown of Wave Loads

Figure 7.3 shows the breakdown of wave loads to inertia and drag forces as it is defined in Morison's equation. It seems that the drag force play more important role in generating wave loads on the jack-up structure. These proportions are related to the Keulegan-carpenter number and are especially sensitive to member diameters and wave height.

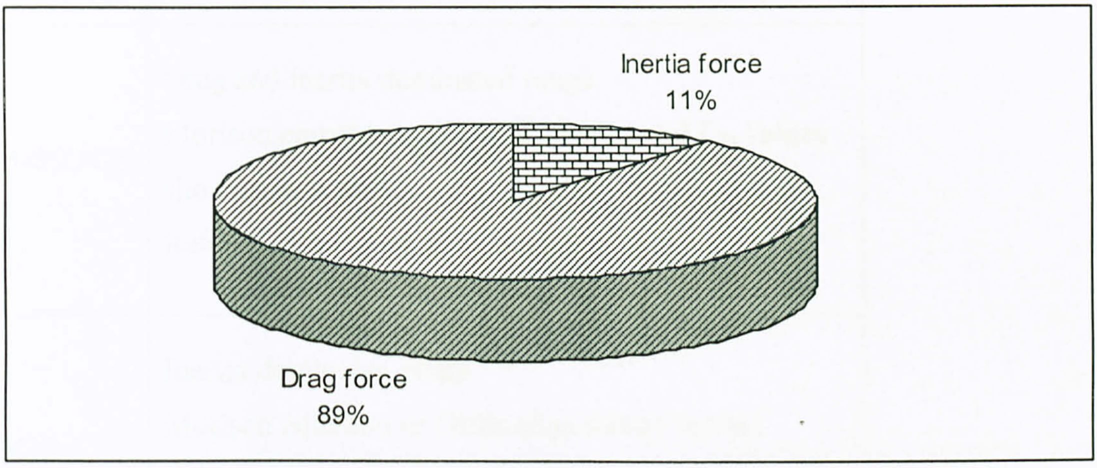


Figure 7.3 Breakdown of wave force to its constituents

As it is mentioned in Chapter 4, the Keulegan-Carpenter number is a non- dimensional parameter that describes the relation between an oscillatory flow and a cylinder:

$$KC = \frac{u_o T}{D}$$

As it is elaborated in Table 7.1, whereas the Keulegan-Carpenter number grows, the drag force becomes dominant and the inertia force becomes less dominant.

According to BASFJOSEL output for MSL model, peak particle velocity is 6.25 m/sec. Hence, KC number is equal to,

$$KC = \frac{6.25 \times 17.7}{0.85} = 130$$

Since the value of KC is greater than 25, the drag force is dominant.

Table 7.1 Guide for evaluation wave load calculation procedures ([1], [17])

KC	D/L<0.2	D/L>0.2
KC>25	Drag dominated Morison equation with C_M and C_D $Re>1.5x10^6$, $C_M=1.8$, $C_D=0.62$ $10^5<Re<1.5x10^6$; $C_M=1.8$, C_D varies form 1.0 to 0.6	Diffraction theory should be used for computing wave forces.
5<KC<25	Drag and inertia dominated range Morison equation applicable, but C_M and C_D values show large scatter. $Re>1.5x10^6$; $C_M=1.8$. $C_D=0.62$	
KC<5	Inertia dominated range Morison equation or Diffraction theory is used $C_M=2.0$ Effect of drag is negligible	

7.1.4 Breakdown of Wind Loads

Figure 7.4 shows the breakdown of wind loads attracted by hull, vertical members (chords) and horizontal and diagonal braces. It is evident that majority of wind loads is attracted by hull. This can be associated to the following reasons:

1. The hull of the jack-up has the largest frontal area in comparison with other members exposed to the wind.
2. Shape coefficient used for the hull is larger than shape coefficient used for other dried members ($C_{s(hull)}=1.5$, $C_{s\,(other\ members)}=0.5$).
3. Hull of the jack-up structure is located at the greater height from Sea Water Level (SWL) and hence it is exposed to the greater wind speed.

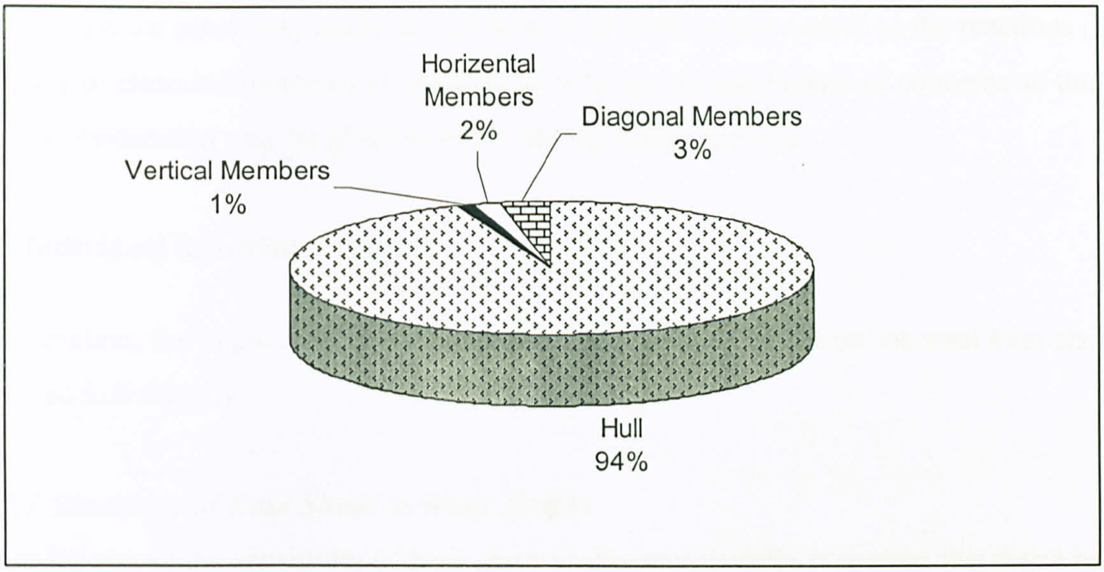


Figure 7.4 Breakdown of wind loads by structural members

It should be mentioned that although diagonal members as a whole attract more wind loads than the vertical members (chords), but the share of each diagonal member in wind load attraction is less than the vertical members. Each vertical member is responsible for about 1.23% / 9 = 0.14% of the total base shear while each of diagonal and horizontal member is responsible for only about 3.10% / 288 = 0.01% and 1.62% / 153 = 0.01 % of the total base shear respectively.

7.2 Sensitivity Analysis of Base Shear

In general, "sensitivity analysis" is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation. Sensitivity Analysis can be used to determine:

- The quality of model definition
- Factors that mostly contribute to the output variability
- The region in the space of input factors for which the model variation is maximum
- Interactions between factors

In this study, the sensitivity analysis was done to determine how sensitive the reactions (base shear and overturning moment) of the Jack-up is to the several factors of concerns so that the proper consideration may be given to them during design process.

7.2.1 Individual Sensitivity Analysis

In this section, the impact of variation in each environmental factor on the total base shear is discussed individually.

7.2.1.1 Sensitivity of Base Shear to Wave Height

Figure 7.5 shows the sensitivity of base shear to the wave height. It is clear that wave height and base shear have a positive relationship as by increasing the wave height, wave forces will increase and hence total base shear will increase. The best fit equation to the curve is $y = 0.0067x^2+1.4123x$.

As it can be observed from the graph, when the wave height is increased by 100%, total base shear is increased by more than 100%. This can be explained by referring to the related formulas. As it is concluded from the previous section, the wave forces make up most of the base shear. Since the wave force is the combination of inertia and drag forces, by referring to equations for Inertia and drag forces, it can be seen that the inertia force is directly proportional to wave height and therefore by doubling the wave height, it will be doubled. Besides, Drag force is proportional to the wave height squared and hence by doubling the wave height it will be quadruple. Therefore, as a whole, by doubling the wave height, total base shear will increase to more than double of its original value.

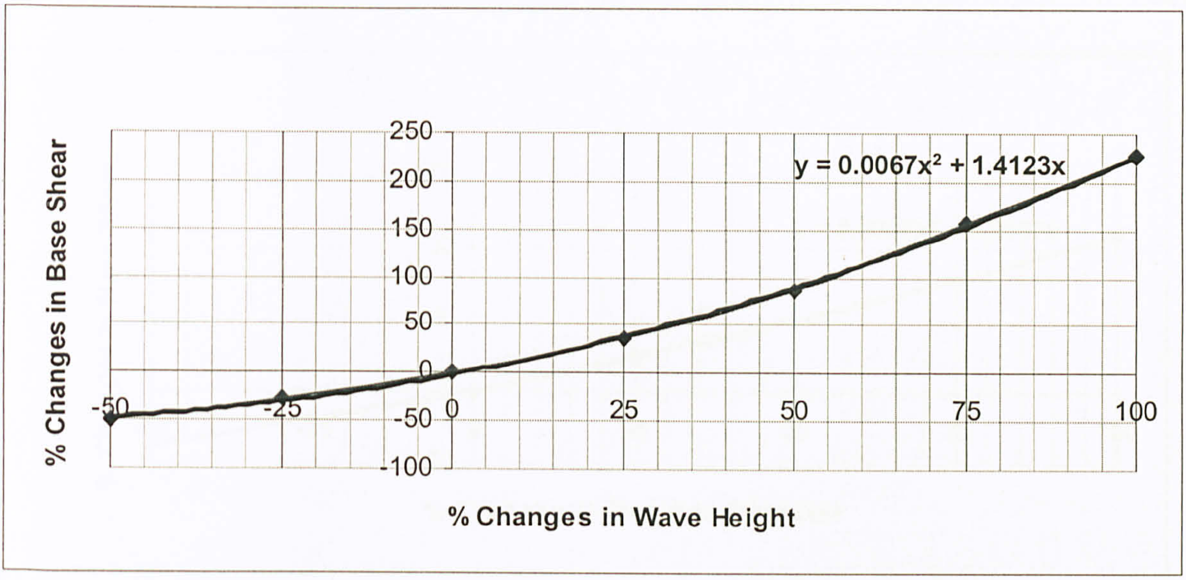


Figure 7.5 Sensitivity of base shear to wave height

7.2.1.2 Sensitivity of Base Shear to Member Diameter

Figure 7.6 shows the sensitivity of base shear to member diameter. As it can be seen, the member diameter and base shear have a positive relationship as by increasing the diameter of the members, the frontal area exposed to the wind, wave and current will increase and hence loads associated to them which are the main constituents of the base shear will increase. The base fit equation to the curve is $y = 0.0007x^2+0.8057x$.

It can be observed that when the member diameter is increased by 100%, total base shear is increased by more than 100% .This can be explained by referring to the analytical formulas. As it is seen before, wave forces make up the most of the base shear. According to Morison's equation, wave force is a combination of inertia force and drag force. Drag force is linearly proportion to the member diameter whilst inertia force is proportional to the member diameter squared. Hence by doubling the diameter of the members, the total shear force will increase to more than double of its original value.

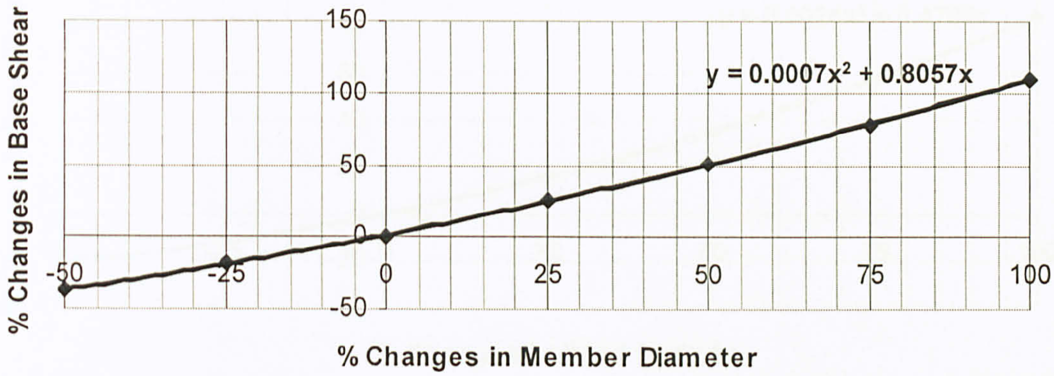


Figure 7.6 Sensitivity of base shear to member diameter

7.2.1.3 Sensitivity of Base Shear to Wind Speed

Figure 7.7 shows the sensitivity of the base shear to the wind speed. It is evident that the base shear is directly proportional to the wind speed as by increasing the wind speed, the drag force applied on the dried part of the structure will increase and as a result, total shear force will increase. The best fit equation for the curve is $y = 0.0024x^2+0.4706x$.

A 100% increase in wind speed leads to an 85% increase in the base shear. This can be justified by reviewing the analytical formulas. It can seen in the output file (Appendix C) that at the baseline wind speed, wind drag constitutes 28% of the entire base shear, and the reaming 72% are the wave and current loads. By doubling the wind speed the wind load will be quadruple from 28% to 112%. Meanwhile the changes in the wind speed will not affect the magnitude of wave and current forces and hence the new base shear is 72%+112%=184%. This result conform the results obtained from the program.

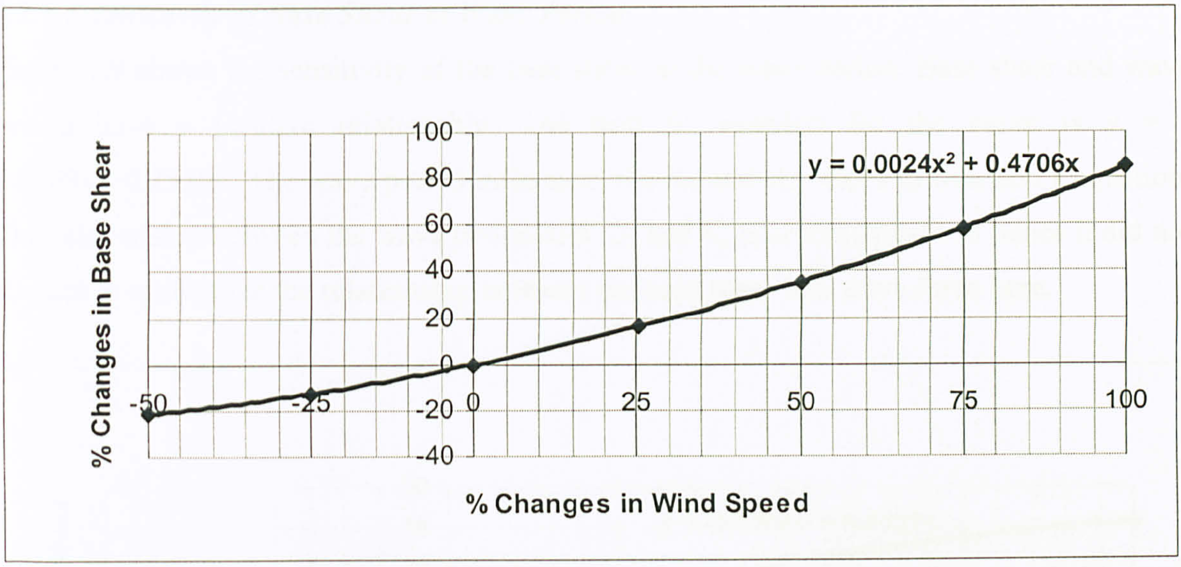


Figure 7.7 Sensitivity of base shear to wind speed

7.2.1.4 Sensitivity of Base Shear to Current Speed

Figure 7.8 shows the sensitivity of base shear to the current speed. It is obvious that the base shear has a direct relationship with current speed as by increasing the current speed, the drag force applied on the structure will increase and as a result total base shear will increase. The best fit equation for the curve is $y = 0.0002x^2+0.0356x$.

As it can be observed from the graph, changing current speed does not cause significant changes in the base shear. This is because current loads constitute only a minor portion of the base shear in comparison to wave and wind forces.

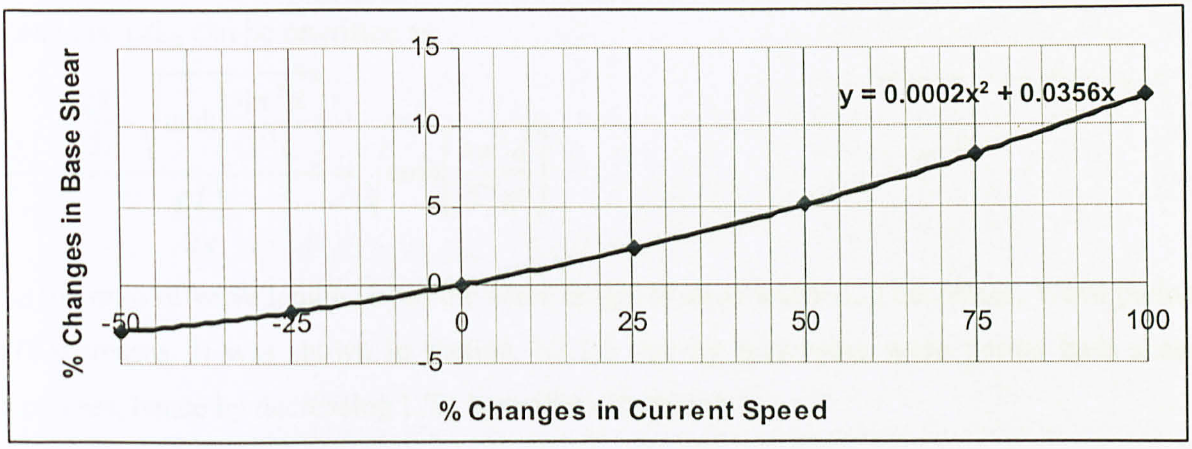


Figure 7.8 Sensitivity of base shear to current speed

7.2.1.5 Sensitivity of Base Shear to Wave Period

Figure 7.9 shows the sensitivity of the base shear to the wave period. Base shear and wave period have a positive relationship. The best fit equation for the curve is $y = -0.0009x^2+0.2556x$. The wave period influences the K_D and K_i values in Morison's equation. The relationship between the wave period and K_D and K_i is complicated and hence it did not attempt to rationalize the relationship between the base shear and wave force here.

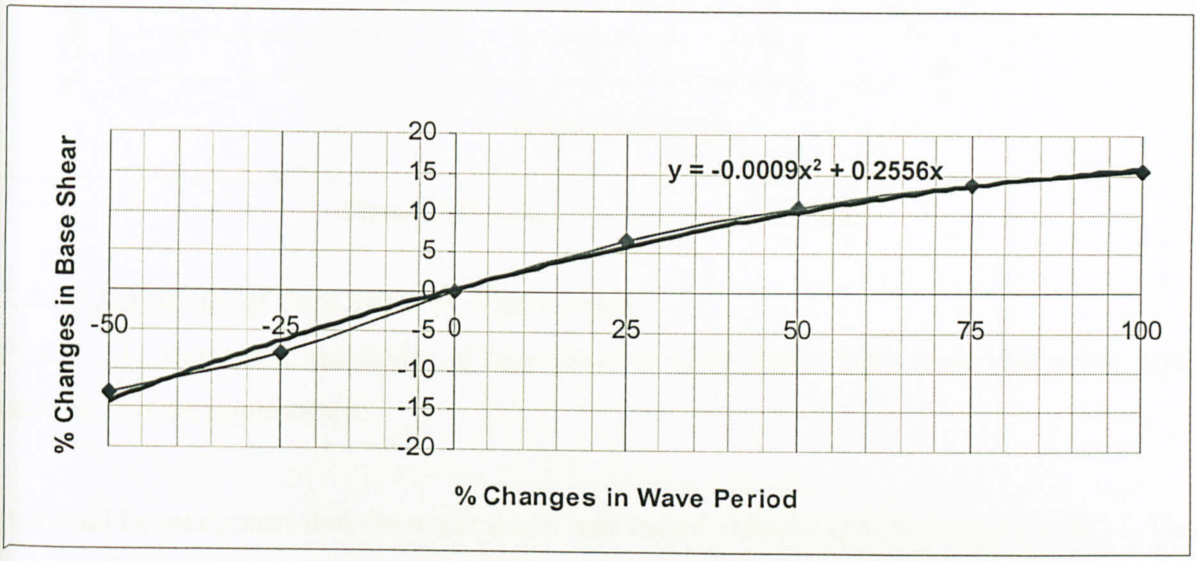


Figure 7.9 Sensitivity of base shear to wave period

7.2.1.6 Sensitivity of Base Shear to Combination of Wave Period and Wave Length

Figure 7.10 shows the sensitivity of base shear to L/L_o. It is clear form the graph that the base shear and L/L_o have an inverse relationship. This can be understood from the analytical formulas. L/L_o can be rewritten as:

$$\frac{L}{L_o} = \frac{\frac{gT^2}{2\pi}\sqrt{\tanh\left[\frac{4\pi^2 d}{T^2 g}\right]}}{\frac{gT^2}{2\pi}} = \sqrt{\tanh\left[\frac{4\pi^2 d}{T^2 g}\right]}$$

As the ratio of wave length (L) to the wave length at deep water (L_o) decreases, Wave period (T) increases. It was shown in section 7.2.1.5 that by increasing wave period base shear increases, hence by decreasing L/L_o base shear increases.

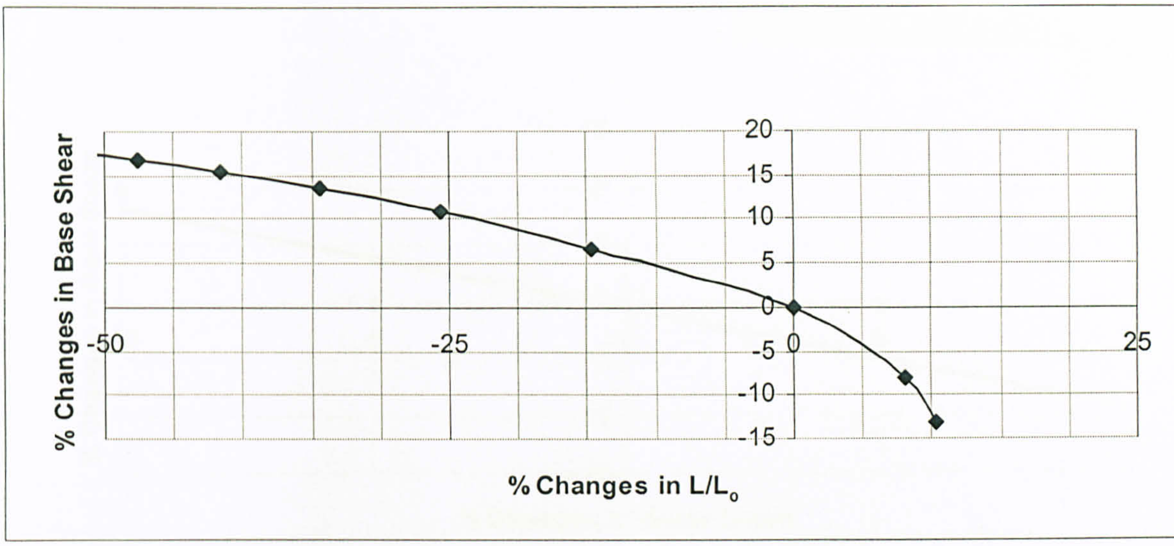


Figure 7.10 Sensitivity of base shear to L/L_o

7.2.1.7 Sensitivity of Base Shear to Water Depth

Figure 7.11 shows the sensitivity of base shear to water depth. Base shear and water depth have an inverse relationship.

It should be mentioned that the water depth was varied within a specific range ($\pm 10\%$). This is because the larger variations would cause water to override the platform. In this situation, redesign of the platform's dimensions is required.

The graph shows that the base shear decreases as the water depth increases. This can be justified by reviewing the analytical formulas. Increasing water depth reduces wind loads by increasing the frontal area exposed to the wind. Trail and error reveals that increasing the water depth decreases n value which in turn decreases K_d and hence decreases drag force. On the other hand, increasing water depth increases K_i and hence inertia force. However since drag force is more dominant than inertia force at the baseline conditions, as a whole, increasing the water depth decreases the wave force.

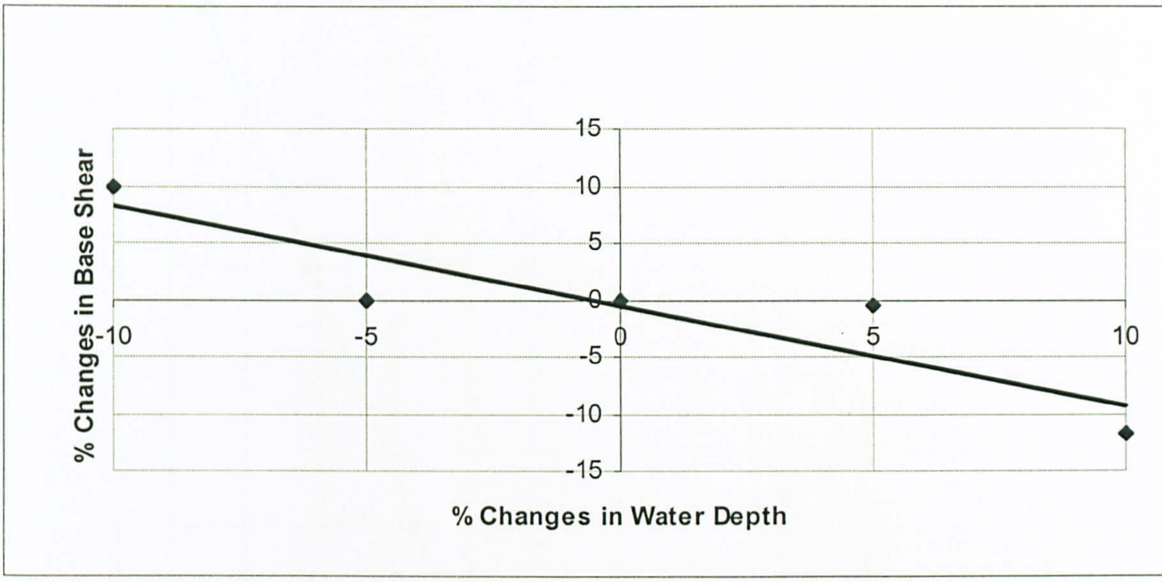


Figure 7.11 Sensitivity of base shear to water depth

7.2.2 Comparative Sensitivity Analysis

Figure 7.12 shows comparison of the sensitivity of the base shear to the different parameters of concern. The following points can be made based on the graph:

1. Base shear has a positive relationship with all plotted parameters except for the water depth and L/L_o.
2. Base shear is the most sensitive to the changes in wave height.
3. The base shear is sensitive to the plotted parameters in the following descending order:
   - Wave height
   - Member diameter
   - Wind speed
   - Current speed
   - Wave period
   - Water depth
   - L/L_o
4. Base shear is more sensitive to the wave height than to member diameters

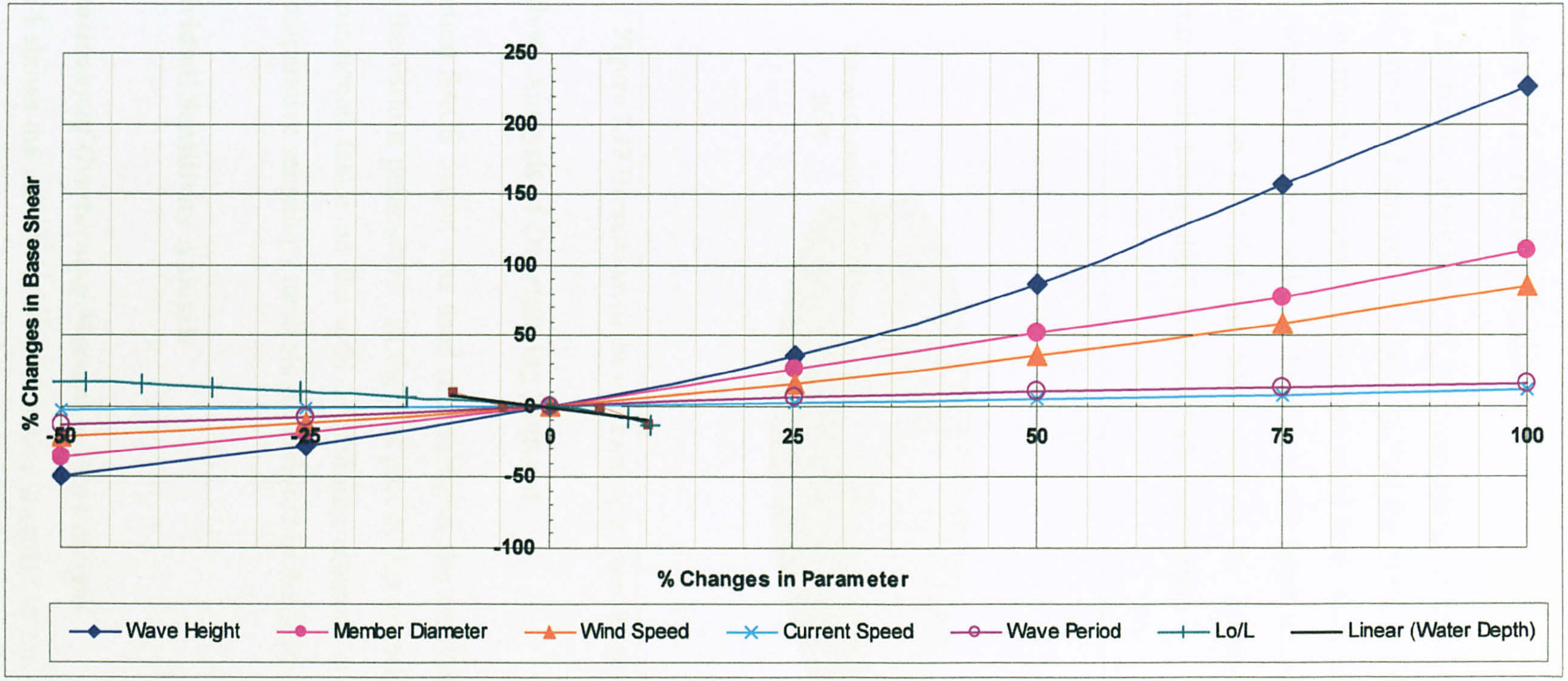


Figure 7.12 Sensitivity of base shear to various environmental parameters

7.3 Breakdown of Overturning Moment

Figure 7.13 shows the breakdown of the overturning moment to the major environmental loads (Wind, wave and current). It is obvious that the contribution of wave and current loads in creating overturning moment is more than wind load. According to definition of moment (M=F x d, where F is force and d is distance to the point where the moment is calculated) and by knowing the fact that the wave load is the dominant load among all major environmental loads, hence, the SACS results is reasonable.

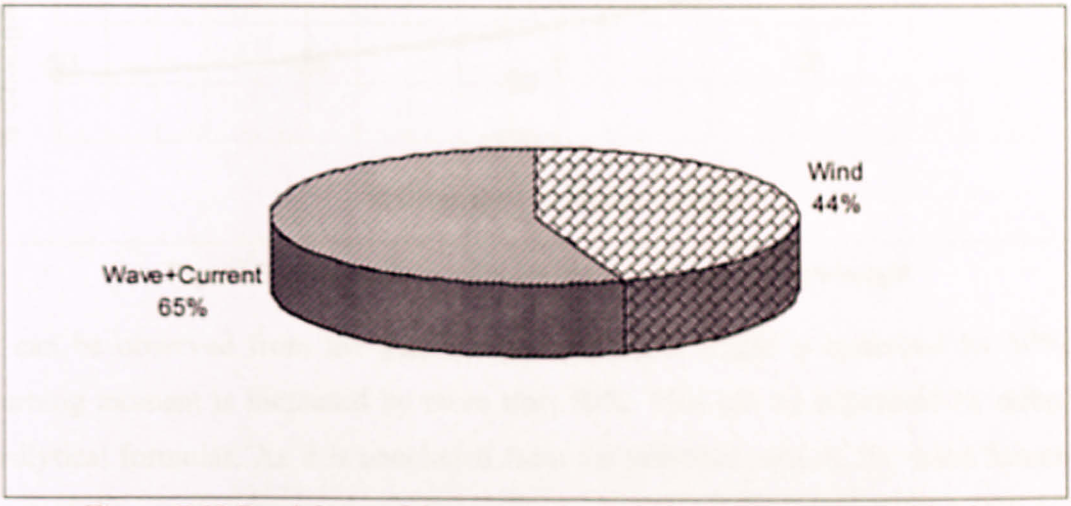


Figure 7.13 Breakdown of the overturning moment by environmental loads

7.4 Sensitivity Analysis of Overturning Moment

In this section SACS output was used to investigate the sensitivity of overturning moment (OTM) to the various parameters. In the first part of this section, the impact of variation in each environmental factor on the total overturning moment is discussed individually and then the comparative sensitivity analysis is conferred in the second part.

7.4.1 Individual Sensitivity Analysis

7.4.1.1 Sensitivity of Overturning Moment to Wave Height

Figure 7.14 shows the sensitivity of overturning moment to the wave height. It is clear that wave height and overturning moment have a positive relationship as by increasing the wave height, wave forces will increase and hence total overturning moment will increase. The best fit equation to the curve is $y = 0.0157x^2 + 2.2109x$.

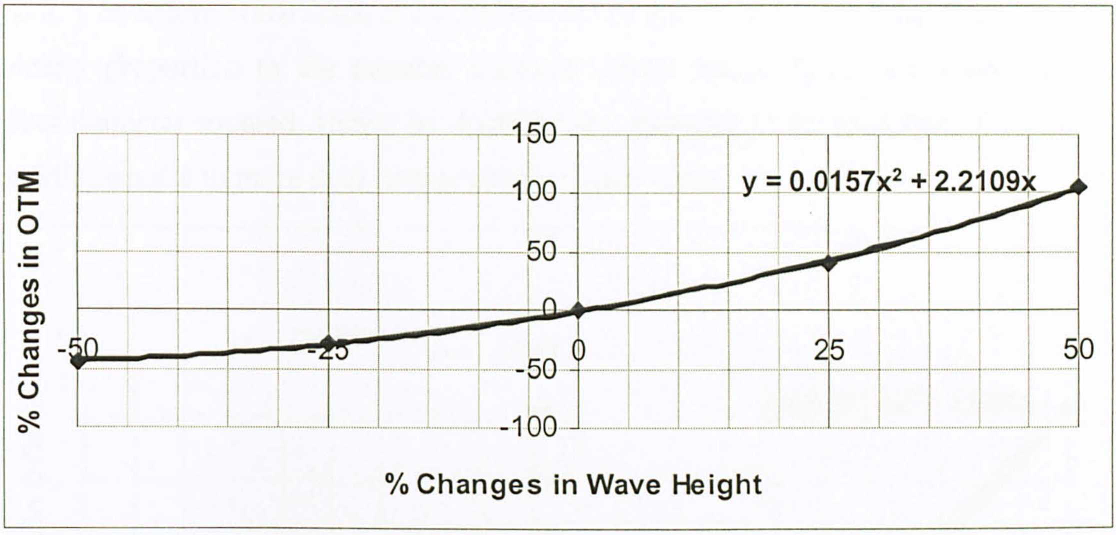


Figure 7.14 Sensitivity of overturning moment to wave height

As it can be observed from the graph, when the wave height is increased by 50%, total overturning moment is increased by more than 50%. This can be explained by referring to the analytical formulas. As it is concluded from the previous section, the wave forces make up most of the overturning moment. Since the wave force is the combination of inertia and drag forces, by referring to equations for Inertia and drag forces, it can be seen that the inertia force is directly proportional to wave height and therefore by doubling the wave height, it will be doubled. Besides, Drag force is proportional to the wave height squared and hence by doubling the wave height it will be quadruple. Therefore, as a whole, by doubling the wave height, total base shear will increase to more than double of its original value.

7.4.1.2 Sensitivity of Base Shear to Member Diameter

Figure 7.15 shows the sensitivity of overturning moment to member diameter. As it can be seen, the member diameter and base shear have a positive relationship as by increasing the diameter of the members, the frontal area exposed to the wind, wave and current will increase and hence loads associated to them which are the main constituents of the base shear will increase. The base fit equation to the curve is $y = 0.0136x^2 + 1.0006x$.

It can be observed that when the member diameter is increased by 50%, total base shear is increased by more than 50% .This can be explained by referring to the analytical formulas. As it is seen before, wave forces make up the most of the overturning moment. According to Morison's equation, wave force is a combination of inertia force and drag force. Drag force is linearly proportion to the member diameter whilst inertia force is proportional to the member diameter squared. Hence by doubling the diameter of the members, the total shear force will increase to more than double of its original value.

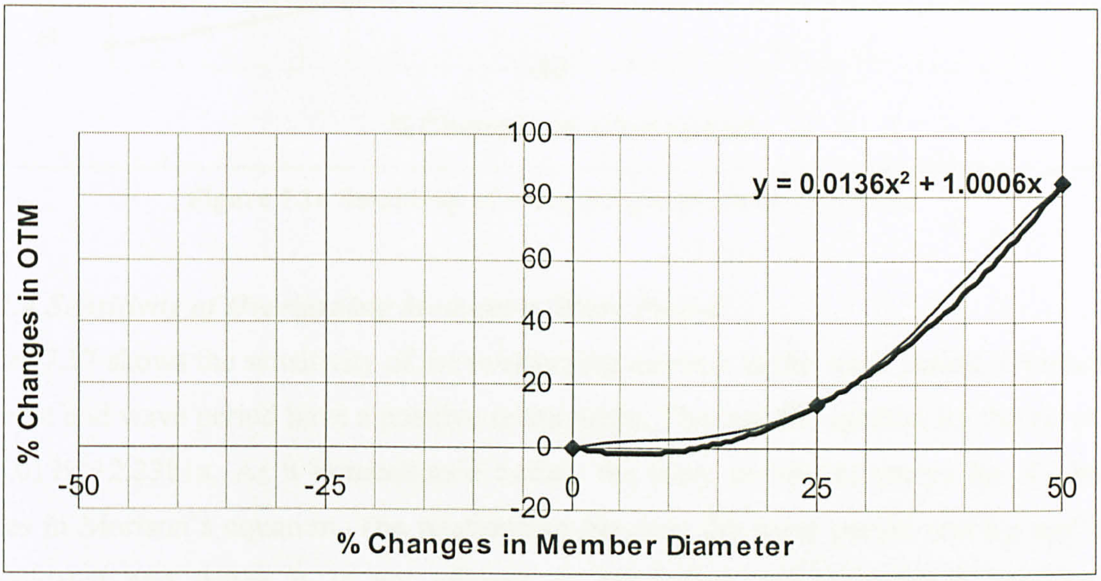


Figure 7.15 Sensitivity of overturning moment to member diameter

7.4.1.3 Sensitivity of Overturning Moment to Wind Speed

Figure 7.16 shows the sensitivity of the overturning moment to the wind speed. It is evident that the overturning moment is directly proportional to the wind speed as by increasing the wind speed, the drag force applied on the dried part of the structure will increase and as a result, total overturning moment will increase. The best fit equation for the curve is $y = 0.0092x^2+1.0401x$.

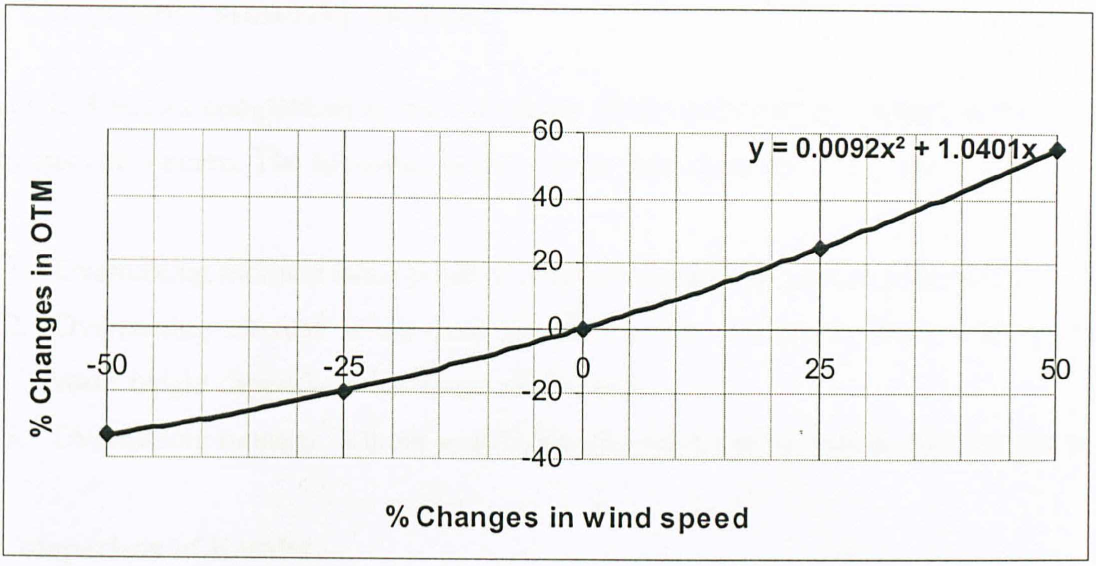


Figure 7.16 Sensitivity of overturning moment to wind speed

7.4.1.4 Sensitivity of Overturning Moment to Wave Period

Figure 7.17 shows the sensitivity of the overturning moment to the wave period. Overturning moment and wave period have a positive relationship. The best fit equation for the curve is y = $-0.017x^2+2.2381x$. As it is mentioned before, the wave period influences the K_D and K_i values in Morison's equation. The relationship between the wave period and K_D and K_i is complicated and hence it is not attempt to rationalize the relationship between the overturning moment and wave period here.

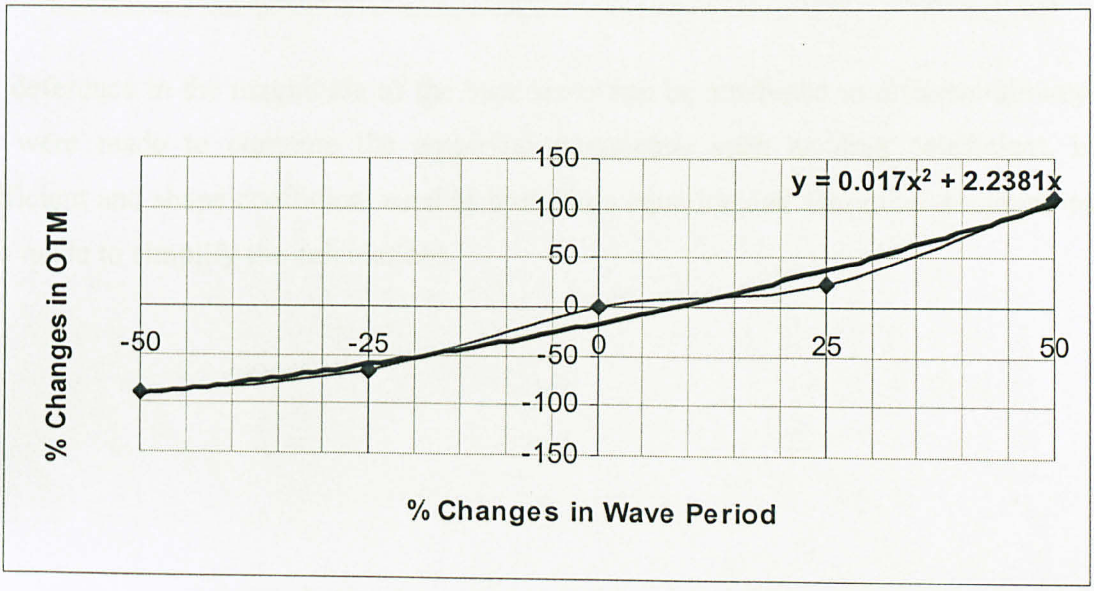


Figure 7.17 Sensitivity of overturning moment to wave period

7.4.2 Comparative Sensitivity Analysis

Figure 7.18 shows comparison of the sensitivity of the overturning moment to the different parameters of concern. The following points can be made based on the graph:

1. Overturning moment has a positive relationship with all plotted parameters.
2. Overturning moment is the most sensitive to the changes in either wave period or wave height depends on the range of changes.
3. Overturning moment is more sensitive to the wave period than to member diameters.

7.5 Comparison of Results

Table 7.2 contains the base shear results obtained from BASFJOSEL as well as SACS. Given the large approximations involved, the comparison showed acceptable similarity for the base shear.

Table 7.2 Comparison of results between SACS and BASFJOSEL

Force	**BASFJOSEL**	**SACS**	**% Difference**
Wind (MN)	2.43	2.46	1.14
Wave + Current (MN)	6.14	6.70	9.07
Total Base Shear (MN)	8.58	9.16	**6.82**

The deference in the magnitude of the base shear can be attributed to different assumptions that were made to compute the empirical parameters such as drag coefficient, inertia coefficient and shape coefficient used in Morison's equation and also other assumptions that were made to simplify the calculations.

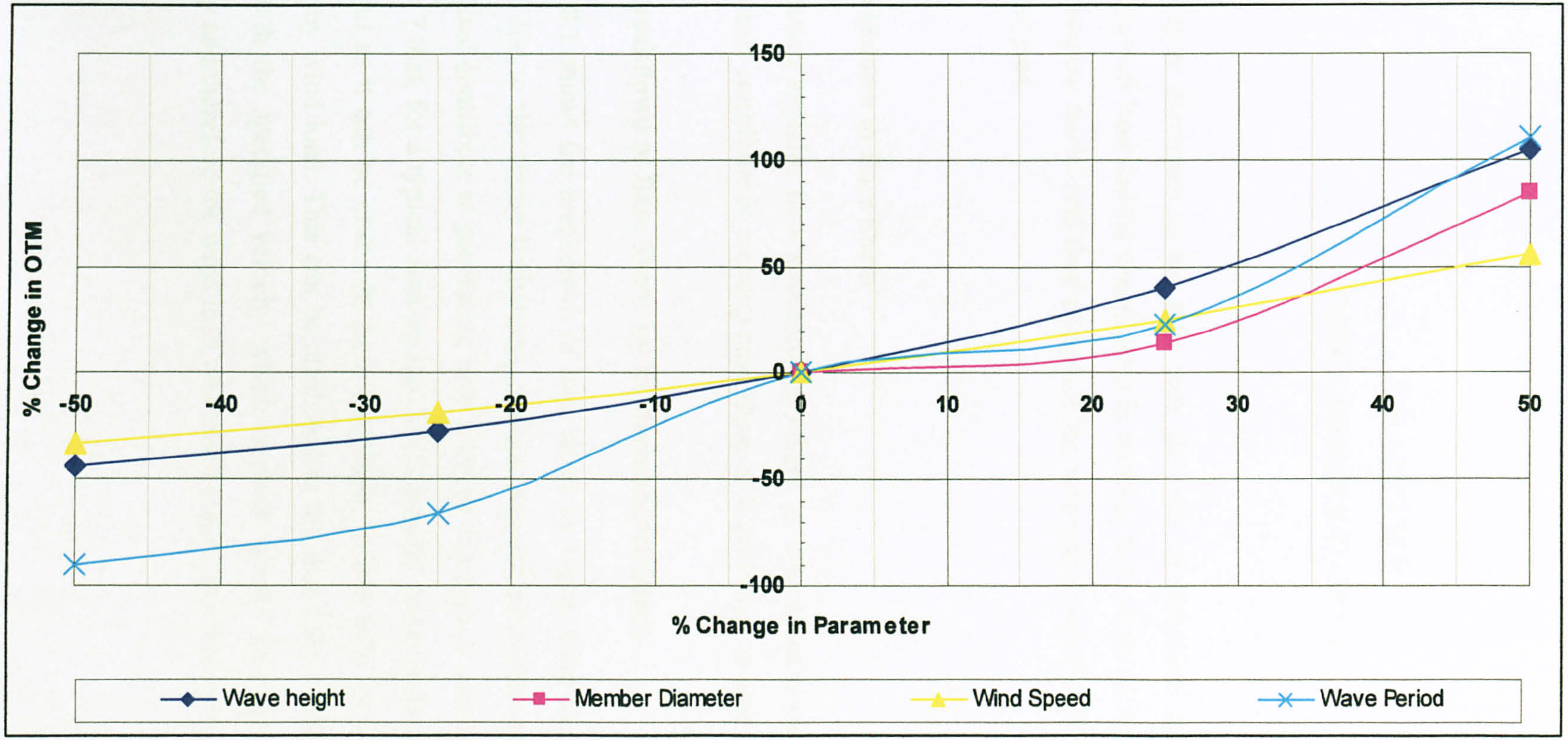


Figure 7.18 Sensitivity of overturning moment to various parameters

CHAPTER 8

DISCUSSIONS-PART II

This chapter discusses at the first part, the role of structural members as well as each environmental load and its constituents in creating base shear using BASFJOSEL output for West Prospero model and then compares the mentioned output with the experimental results in second part.

8.1 Breakdown of Base Shear

This section explains how structural members as well as each environmental load and its constituents contribute in creating base shear in West Prospero model.

8.1.1 Breakdown of Base Shear by Environmental Loads

Figure 8.1 shows the breakdown of base shear by wave, wind loads. As it was mentioned earlier, due to the flume limitations, current was not simulated and hence only wind and waves load contribute in generating base shear in this case. It was seen from section 7.1.1 in chapter 7 that, for a typical Jack-up like MSL, usually wave loads make up most of the base shear but as it can be observed from the graph, in this case the majority of base shear is caused by wind load. This can be attributed to the fact that, conventional fan can generate wind with the specified velocity which is much greater than the calculated scaled wind velocity and therefore the wind load was much greater than the typical condition.

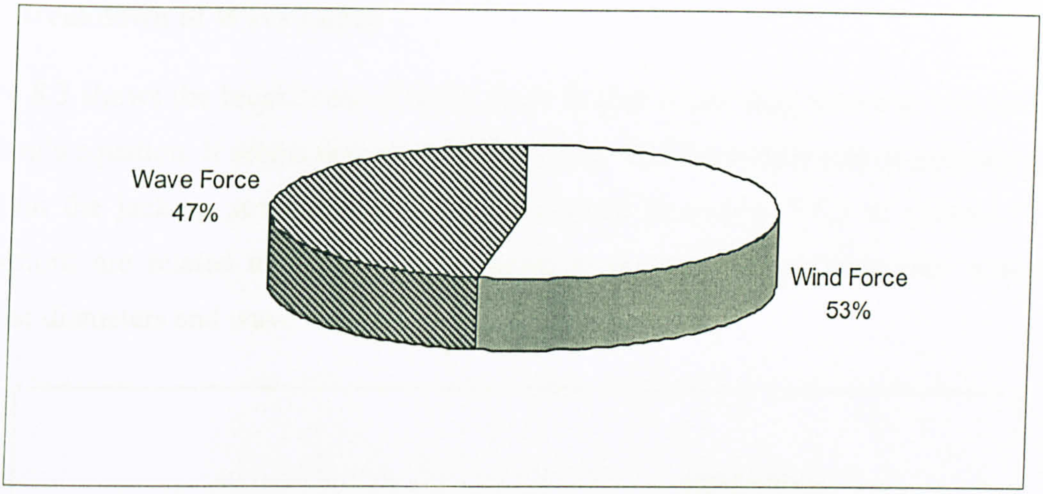


Figure 8.1 Breakdown of base shear by environmental loads

8.1.2 Breakdown of Base Shear by Structural Members

Figure 8.2 shows the breakdown of base shear by structural members. Since in this case study the contribution of wind load in creating base shear is more wave and also hull has the largest exposed area in comparison with other structural members, it is logical that hull contribute the most in generating base shear as it is shown in the graph.

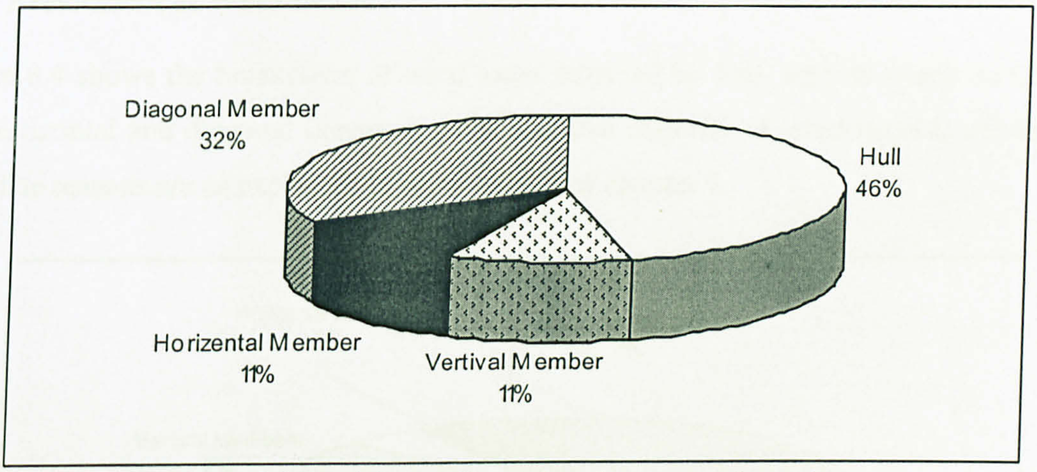


Figure 8.2 Breakdown of base shear by structural members

8.1.3 Breakdown of Wave Loads

Figure 8.3 shows the breakdown of wave loads to inertia and drag forces as it is defined in Morison's equation. It seems that the drag force play more important role in generating wave loads on the jack-up structure. As it was explained in section 7.1.3 of chapter 7, these proportions are related to the Keulegan-carpenter number and are especially sensitive to member diameters and wave height.

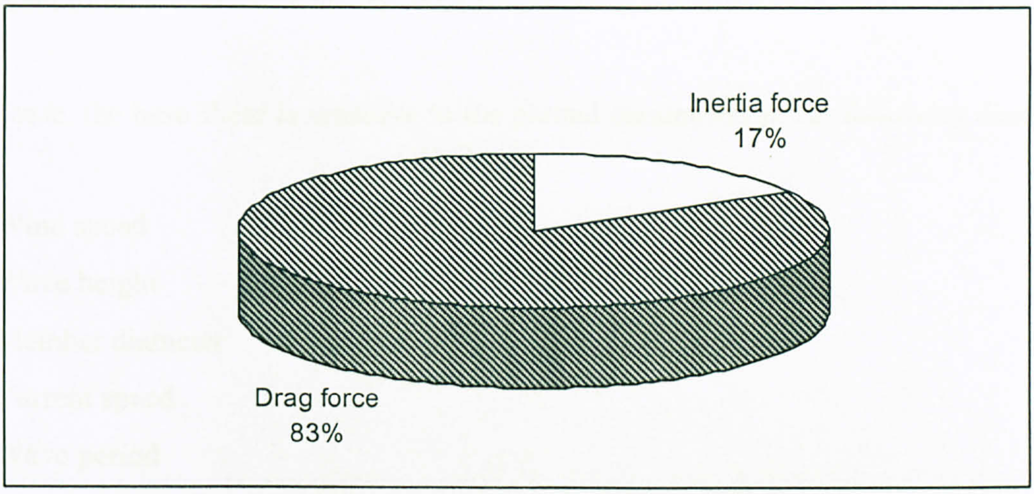


Figure 8.3 Breakdown of wave force to its constituents

8.1.4 Breakdown of Wind Loads

Figure 8.4 shows the breakdown of wind loads attracted by hull, vertical members (chords) and horizontal and diagonal braces. It is evident that majority of wind loads is attracted by hull. The reasons are as explained in section 7.1.5 of chapter 7.

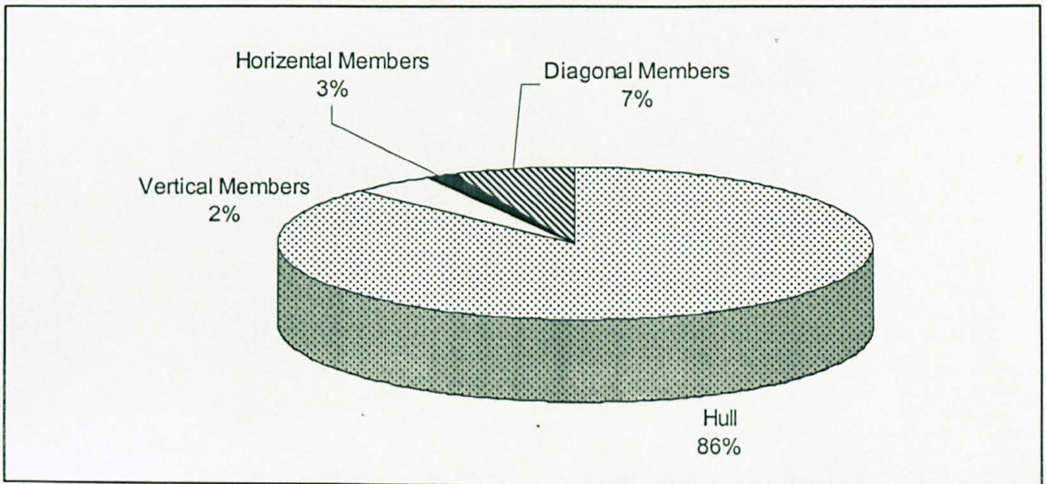


Figure 8.4 Breakdown of wind loads by structural members

8.2 Sensitivity Analysis of Base Shear

The sensitivity graph in Figure 8.5 shows comparison of the West Prospero base shear to the different parameters of concern. The trend of the curves show close similarity with MSL model except for the wind speed. It can be observed from the graph that base shear is most sensitive to the wind speed rather than wave height. This can be contributed to the fact that in this case, wind load make up most of the base shear and wind speed is one of the main constituent of it.

In this case, the base shear is sensitive to the plotted parameters in the following descending order:

- Wind speed
- Wave height
- Member diameter
- Current speed
- Wave period
- Water depth
- L/L_o

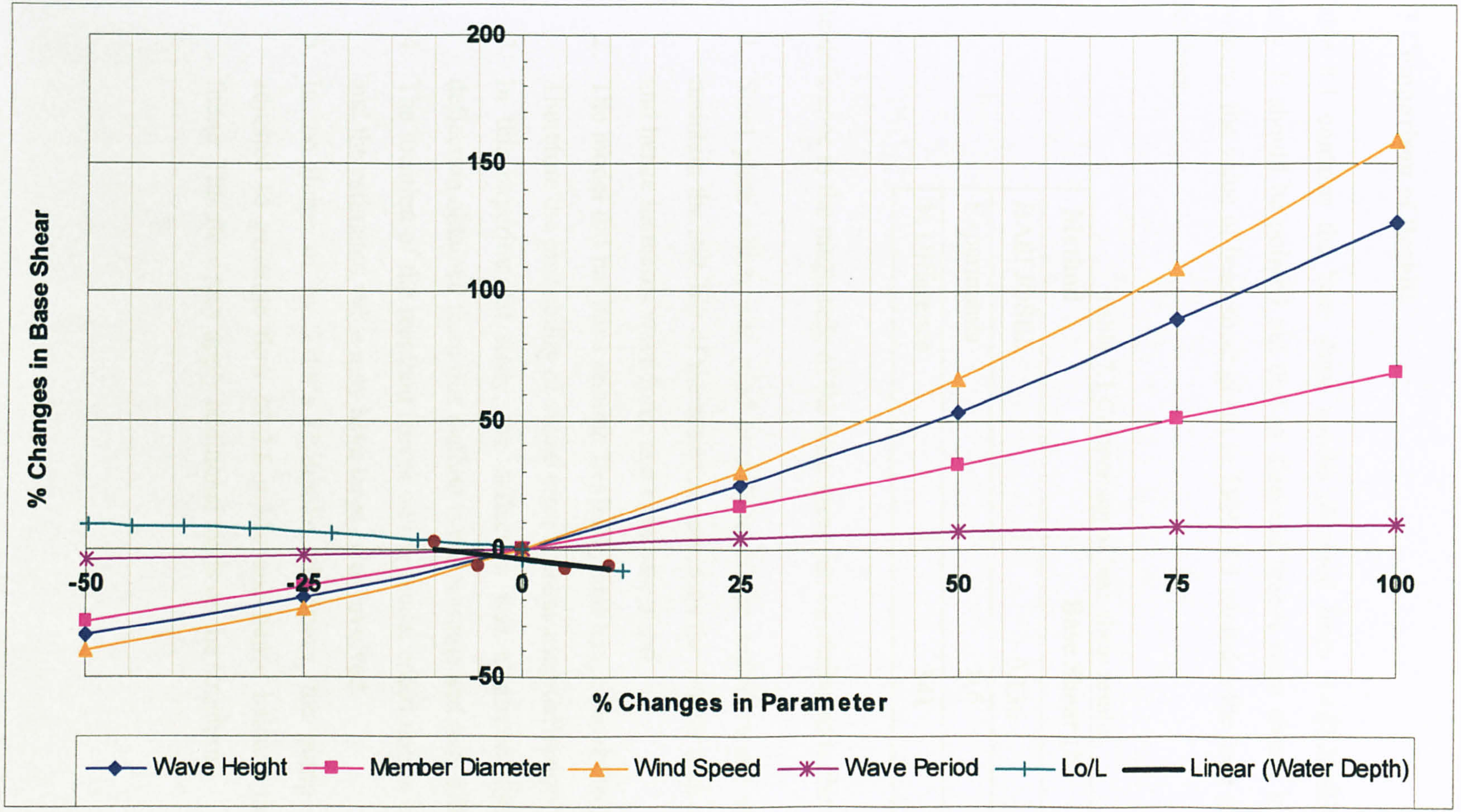


Figure 8.5 Sensitivity of base shear to various environmental parameters

8.3 Comparison of Results

Table 8.1 contains the base shear results obtained from BASFJOSEL and experimental study. It should be pointed out that as diagonal braces were absent in the model of West Prospero, the value of base shear given in Table 8.1 excludes the base shear caused by these members.

Table 7.1 Comparison of base shear results

Method	Base Shear (N)
BASFJOSEL	0.136
Experiments	0.6
% Difference	**341**

The deference in the magnitude of the base shear can be attributed to the following reasons:

1. Steel plate which was used as a base of the scaled model of West Prospero to maintain the stability of the structure increases the frontal area exposed to the wave and hence increases wave force and total base shear.
2. The model did not have enough flexibility and hence the deflection was very small. Therefore the probability of visual error in measuring deflection was high.
3. In this experimental study, the deflection was measured visually. The value of deflection obtained from this method is not accurate and may affect the results.
4. The location of the resultant forces on the model could not be calculated accurately and the estimated value may have large error involved.
5. In the flume of the UTP's Hydraulic laboratory, the pump was turned on and adjusted to generate flow of 2.6 m3/hr and hence balance the leakage from the flume. This flow may apply additional loads on the structure.

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the summary of main points obtained from this research and recommendation for future works.

The summary of key points obtained from this study is as follows:

1. Given the large approximations involved, the comparison showed acceptable similarity for the base shear between SACS and in-BASFJOSEL.
2. The breakdown of the base shear force and overturning moment in terms of contributions from three environmental loads pertaining to wave, current and wind revealed the dominant role of the wave forces for real-life design conditions.
3. Examination of the values and ratios of wave action to the members, wind action to the hull and to the dry members in the air gap, and current action to various members showed that among the wave parameters (height H, period T), H causes greater impact on the base shear whilst the overturning moment show maximum sensitivity to H only when increase of the parameters is considered. With the decrease of the parameters, the overturning moment and platform deflection are the most sensitive to T rather than to H, D and wind speed.
4. It also revealed that the significance of the wave height is even greater than the role of the member diameters in the total value of the base shear force as well as overturning moment.
5. Numerous applications of BASFJOSEL and comparison with SACS software and experimental results have proved that in the absence of the specialized expensive simulator, the program is useful means in preliminary checks during the conceptual design of the Jack-up structures as well as educational purposes requiring quick calculations of the total forces.

In order to get accurate experimental results, it is suggested to use strain gauge on the main members of the scaled model during the experiments. The results obtained from the strain gauge can be transferred to the base shear and overturning moment and these values will be more reliable. It is also recommended to perform the physical modelling test in the new wave basin at UTP's coastal laboratory.

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APPENDIXES

Appendix A

Basic equations used in Linear Airy theory

Relative Depth	Shallow Water $\frac{d}{L} < \frac{1}{20}$ $kd < \frac{\pi}{10}$	Transitional Water $\frac{1}{20} < \frac{d}{L} < \frac{1}{2}$ $\frac{\pi}{10} < kd < \frac{\pi}{2}$	Deep Water $\frac{d}{L} > \frac{1}{2}$ $kd > \frac{\pi}{2}$
1. Wave profile	Same As >	$\eta = \frac{H}{2}\cos\left[\frac{2\pi x}{L} - \frac{2\pi t}{T}\right] = \frac{H}{2}\cos\theta$	< Same As
2. Wave celerity	$C = \frac{L}{T} = \sqrt{gd}$	$C = \frac{L}{T} = \frac{gT}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$C = C_0 = \frac{L}{T} = \frac{gT}{2\pi}$
3. Wavelength	$L = T\sqrt{gd} = CT$	$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$	$L = L_0 = \frac{gT^2}{2\pi} = C_0 T$
4. Group velocity	$C_g = C = \sqrt{gd}$	$C_g = nC = \frac{1}{2}\left[1 + \frac{4\pi d/L}{\sinh(4\pi d/L)}\right]C$	$C_g = \frac{1}{2}C = \frac{gT}{4\pi}$
5. Water particle velocity (a) Horizontal	$u = \frac{H}{2}\sqrt{\frac{g}{d}}\cos\theta$	$u = \frac{H}{2}\frac{gT}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$u = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
(b) Vertical	$w = \frac{H\pi}{T}\left(1+\frac{z}{d}\right)\sin\theta$	$w = \frac{H}{2}\frac{gT}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$w = \frac{\pi H}{T}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
6. Water particle accelerations (a) Horizontal	$a_x = \frac{H\pi}{T}\sqrt{\frac{g}{d}}\sin\theta$	$a_x = \frac{g\pi H}{L}\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\sin\theta$	$a_x = 2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$a_z = -2H\left(\frac{\pi}{T}\right)^2\left(1+\frac{z}{d}\right)\cos\theta$	$a_z = -\frac{g\pi H}{L}\frac{\sinh[2\pi(z+d)/L]}{\cosh(2\pi d/L)}\cos\theta$	$a_z = -2H\left(\frac{\pi}{T}\right)^2 e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
7. Water particle displacements (a) Horizontal	$\xi = -\frac{HT}{4\pi}\sqrt{\frac{g}{d}}\sin\theta$	$\xi = -\frac{H}{2}\frac{\cosh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\sin\theta$	$\xi = -\frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\sin\theta$
(b) Vertical	$\zeta = \frac{H}{2}\left(1+\frac{z}{d}\right)\cos\theta$	$\zeta = \frac{H}{2}\frac{\sinh[2\pi(z+d)/L]}{\sinh(2\pi d/L)}\cos\theta$	$\zeta = \frac{H}{2}e^{\left(\frac{2\pi z}{L}\right)}\cos\theta$
8. Subsurface pressure	$p = \rho g(\eta - z)$	$p = \rho g\eta\frac{\cosh[2\pi(z+d)/L]}{\cosh(2\pi d/L)} - \rho gz$	$p = \rho g\eta\, e^{\left(\frac{2\pi z}{L}\right)} - \rho gz$

Figure II-1-9. Summary of linear (Airy) wave theory - wave characteristics

Appendix B

BASFJOSEL Output for West Prospero Model

Title:	West Prospero- Inputs
Type of Platform:	Jack up offshore structure- West Prospero Model
Location:	Malaysia's Jerneh and Tapis fields, off east coast peninsular Malaysia
Done by:	Sanam Aghdamy/6154
Date of Modification:	22.03.2008

GIVEN DATA:

DIMENSIONS OF PLATFORM:

Hull:

Type of hall:	0	
Length=	0.285	m
Width=	0.253	m
Depth=	0.048	m

Figure 1

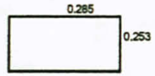


Figure 2

Figure 1 shows the plan view of hull

Leg:

Number of legs=	3		
Type of Legs/ Number of chords=	0 3		
Usable leg below hull(including spud can)=	0.476 m		
Leg penetration=	0.104 m		
Overal leg length(including spud can)=	0.524 m		
Leg length bellow WL(including spud can)	0.364 m		
Leg length above WL(air gap)	0.112 m		
Leg spacing=	Transverse:	0.173	m
	Longitudinal:	0.157	m
	Total	0.234	m
Diameter of vertical member=	0.0030 m		

Lengths of horizental member (For leg type 0 & 1 only)=

L-1(m)	L-2(m)
0.0200	0.0200

Diameter of horizental member (For leg type 0 & 1 only)= 0.0020 m

Length of diagonal member (For leg type 0 & 1 only)=

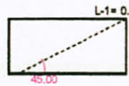
L-3(m)	L- 4(m)
0.0316	0.0316

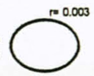
Diameter of diaginal member (For leg type 0 & 1 only)= 0.0020 m

Angles of diagonal member with horizental (For leg type 0 & 1 only)=

L-3(m)	L- 4(m)
71.6	71.6

Vertical spacing between horizental members(For leg type 0 & 1 only)= 0.0300 m





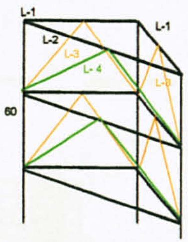


Figure 3

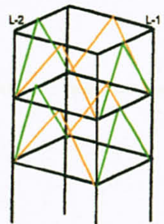
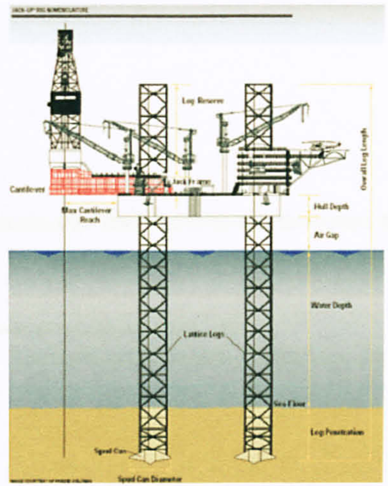


Figure 4

Figure 5

Figure 3 shows the plan view and side view of leg



Spud can:

Spud can diameter= 0.0570 m

ENVIRONMENTAL PARAMETERS:

Water depth including storm surge	0.2600 m			
Maximum wave height	0.0660 m			
Period of the 100-year wave	0.8400 sec			
Associated current speed at the surface	0.0000 m/sec			
Maximum wind speed at 10m above SWL	4.4000 m/sec			
Soil type	Sand			
Density of water=	1020 Kg/m^3	when temperature=	15.6	^oC
Density of air=	1.225 Kg/m^3	when temperature=	15	^oC
Direction of wind=	Default			

Marine growth (m)=

Between	0	to	-0.26	0
Between	-	to	-	-

=	0.001002 $N.Sec/m^2$	when temperature=	15	^oC
C_s (top side)=	1.5			
C_s (Dry part)=	0.5			
C_M =	2			
C_D =	1.2			

CALCULATED INPUT:

WAVE CHARACTERISTICS:

L_o=		1.10 m					
L=		1.02 m					
d/L=		0.2558 Transitional water					
Wave length=		1.02 m					
Wave Speed=		1.21 m/s					
Group number, n=		0.63					
Max. water particle velocityat SWL:				Max. water particle velocityat sea-bed=			
	Horizental=	0.27 m/s	Z= 0	Horizental=	0.10 m/s	Z=	-0.26
	Vertical=	0 m/s	θ= 0	Vertical=	0.00 m/s	θ=	0
	Total=	0.27 m/s		Total=	0.10 m/s		
Max. water particle acceleration at SWL=				Max. water particle acceleration atsea-bed=			
	Horizental=	0.00 m/s^2		Horizental=	0.00 m/s^2		
	Vertical=	1.85 m/s^2		Vertical=	0.00 m/s^2		
	Total=	1.85 m/s^2		Total=	0.00 m/s^2		
K_i=		0.46					
K_D=		0.16					

OTHERS:

Number of Memebrs:

No. of vertical members=		**9**							
No. of horizental braces=		**126**							
	No of horizental braces above WL=	36							
	No of horizental braces bellow WL=	90							
No. of diagonal braces=		**234**							
	No of diagonal braces above WL=	54							
	No of diagonal braces partially submerged =	1	Length of each brace that is not submerged(L3)-	0.02	Length of brace that is submerged(	0.01	Length of each brace that is not submerged(L4)-r	0.02	Length of brace that is submerged(L4)-m= 0.01
	No of diagonal braces Fully submerged =	179							
No. of Spudcan=		**3**							

Exposed Areas:

Wind exposed area:	Area (m2)	No.	Total (m2)
Hull=	0.0137	1.0000	0.0137
Vertical member=	0.0003	9.0000	0.0030
Horizental braces=	0.0000	12.0000	0.0005
diagonal braces=	0.0001	72.0000	0.0046
TOTAL=			0.0217

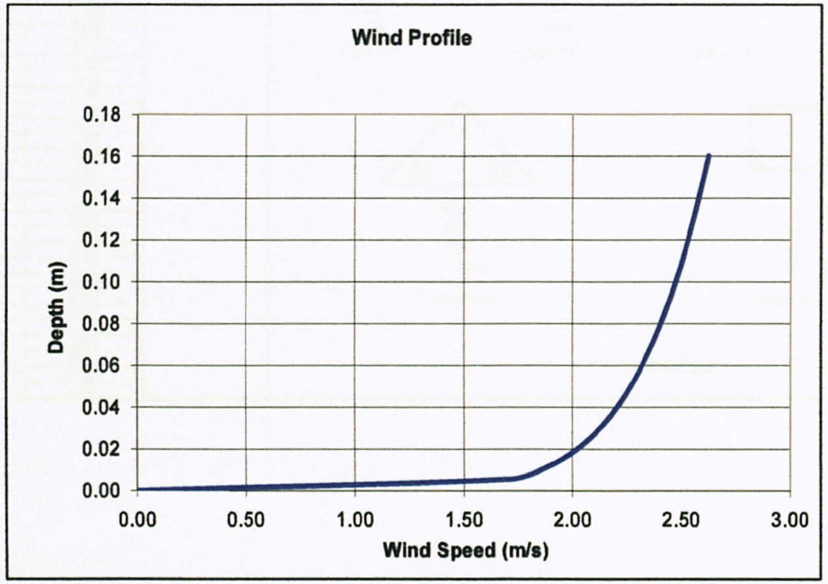
Wave & Current exposed area:	Hieght (m)		Area (m2)	No	Total (m2)
	From	To			
Vertical member=	0.0000	-0.2600	0.00078	9.00000	0.00702
	-	-	-	-	0.00000
Horizental braces=	0.0000	-0.2600	0.00004	27.00000	0.00108
	-	-	-	-	0.00000
Diagonal braces=	0.0000	-0.2600	0.00006	144.00000	0.00911
	-	-	-	-	0.00000
TOTAL=					0.0172

Title: West Prospero-Wind Profile
Type of Platform: Jack up offshore structure- West Prospero Model
Location: Malaysia's Jerneh and Tapis fields, off east coast peninsular Malaysia
Done by: Sanam Aghdamy/6154
Date of Modification: 22.03.2008

WIND PROFILE:

Total Heigth above WL= 0.16 m
Selected height internal= 0.0053 m
Wind at 10m above WL= 4.4 m/sec
n= 8

Height(m)	Wind speed(m/sec)
0.1600	2.62
0.1547	2.61
0.1493	2.60
0.1440	2.59
0.1387	2.58
0.1333	2.56
0.1280	2.55
0.1227	2.54
0.1173	2.52
0.1120	2.51
0.1067	2.49
0.1013	2.48
0.0960	2.46
0.0907	2.44
0.0853	2.43
0.0800	2.41
0.0747	2.39
0.0693	2.36
0.0640	2.34
0.0587	2.31
0.0533	2.29
0.0480	2.26
0.0427	2.22
0.0373	2.19
0.0320	2.15
0.0267	2.10
0.0213	2.04
0.0160	1.97
0.0107	1.87
0.0053	1.72
0.0000	0.00



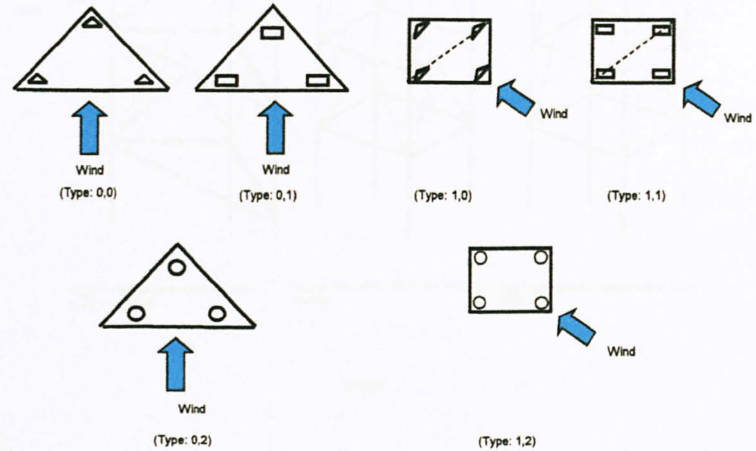
Title:	West Prospero-Wind Force
Type of Platform:	Jack up offshore structure- West Prospero Model
Location:	Malaysia's Jerneh and Tapis fields, off east coast peninsular Malaysia
Done by:	Sanam Aghdamy/6154
Date of Modification:	22.03.2008

OUTPUT:

WIND FORCE:

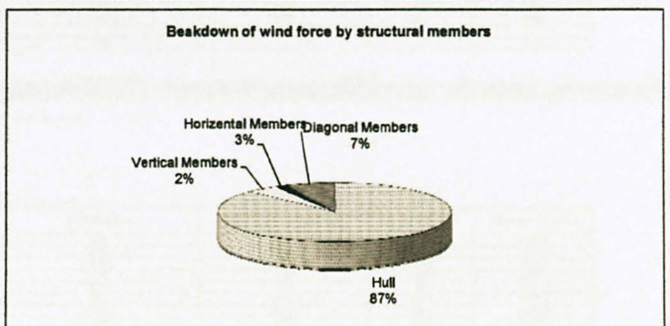
Wind Force

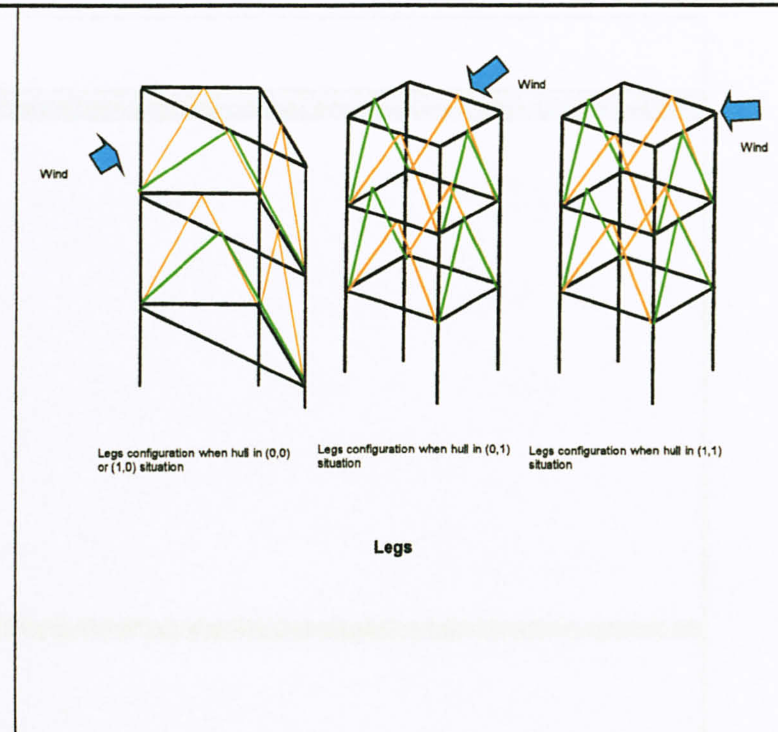
Height (m)		Wind Velocity (m/Sec)	Component	Force (N)
From	To			Total
0.15	0.16	2.62	Hull	0.010
			Leg	0.000
0.15	0.15	2.61	Hull	0.010
			Leg	0.000
0.14	0.15	2.60	Hull	0.009
			Leg	0.000
0.14	0.14	2.59	Hull	0.009
			Leg	0.000
0.13	0.14	2.58	Hull	0.009
			Leg	0.000
0.13	0.13	2.56	Hull	0.009
			Leg	0.000
0.12	0.13	2.55	Hull	0.009
			Leg	0.000
0.12	0.12	2.54	Hull	0.009
			Leg	0.000
0.11	0.12	2.52	Hull	0.009
			Leg	0.000
0.11	0.11	2.51	Hull	0.009
			Leg	0.001
0.10	0.11	2.49	Hull	0.000
			Leg	0.001
0.10	0.10	2.48	Hull	0.000
			Leg	0.001
0.09	0.10	2.46	Hull	0.000
			Leg	0.001
0.09	0.09	2.44	Hull	0.000
			Leg	0.001
0.08	0.09	2.43	Hull	0.000
			Leg	0.001
0.07	0.08	2.41	Hull	0.000
			Leg	0.001



Top side/Hull

0.07	0.07	2.39	Hull	0.000
			Leg	0.001
0.06	0.07	2.36	Hull	0.000
			Leg	0.001
0.06	0.06	2.34	Hull	0.000
			Leg	0.001
0.05	0.06	2.31	Hull	0.000
			Leg	0.001
0.05	0.05	2.29	Hull	0.000
			Leg	0.001
0.04	0.05	2.26	Hull	0.000
			Leg	0.001
0.04	0.04	2.22	Hull	0.000
			Leg	0.001
0.03	0.04	2.19	Hull	0.000
			Leg	0.001
0.03	0.03	2.15	Hull	0.000
			Leg	0.001
0.02	0.03	2.10	Hull	0.000
			Leg	0.001
0.02	0.02	2.04	Hull	0.000
			Leg	0.000
0.01	0.02	1.97	Hull	0.000
			Leg	0.000
0.01	0.01	1.87	Hull	0.000
			Leg	0.000
0.00	0.01	1.72	Hull	0.000
			Leg	0.000
Total Force (N)=				0.106
Total Force act on the Hull (N)=				0.092
Total Forces act on Leg (N)=				0.014
Total Force act on the vertical member (N)=				0.005
Total Force act on the Horizental l member (N)=				0.002
Total Force act on the diagonal l member (N)=				0.007





Title: West Prospero-Wave Force
Type of Platform: Jack up offshore structure- West Prospero Model
Location: Malaysia's Jerneh and Tapis fields, off east coast peninsular Malaysia
Done by: Sanam Aghdamy/6154
Date of Modification: 03.04.2008

WAVE FORCE

INERTIA FORCE-Fi

For Vertical Member:

Fi= 0.0043 N

For Horizental Member:

Water Depth(m)	Water Particle Acceleration (m/s^2)	Inertia force-Fi (N)/m	Inertia force-Fi (N)/leg
0.25	1.75	0.0112	0.0007
0.22	1.42	0.0091	0.0005
0.19	1.15	0.0073	0.0004
0.16	0.91	0.0058	0.0003
0.13	0.70	0.0045	0.0003
0.10	0.52	0.0033	0.0002
0.07	0.35	0.0023	0.0001
0.04	0.20	0.0013	0.0001
0.01	0.06	0.0004	0.0000
-	-	-	-
Total			0.0027

For Diagonal Member:

Water Depth(m)	Water Particle Acceleration (m/s^2)	Inertia force-Fi (N)/m	Inertia force-Fi (N)/leg
0.24	1.58	0.010	0.002
0.21	1.28	0.008	0.002
0.18	1.02	0.007	0.001
0.15	0.80	0.005	0.001
0.12	0.61	0.004	0.001
0.09	0.44	0.003	0.001
0.06	0.28	0.002	0.000
0.03	0.13	0.001	0.000
-	-	-	-
Total			0.008

Total Inertia Force= 0.016 N

DRAG FORCE-F_D

For Vertical Member:

F_D= 0.01 N

For Horizental Member:

Water Depth(m)	Water Particle Velocity (m/s)	Drag force-F_D (N)/m	Drag force-FD (N)/leg
0.25	0.26	0.080	0.0048
0.22	0.22	0.057	0.0034
0.19	0.18	0.042	0.0025
0.16	0.16	0.031	0.0019
0.13	0.14	0.024	0.0014
0.10	0.12	0.019	0.0011
0.07	0.11	0.016	0.0009
0.04	0.11	0.014	0.0008
0.01	0.10	0.013	0.0008
-	-	-	-
Total			0.02

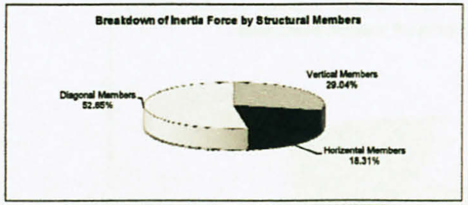
For Diagonal Member:

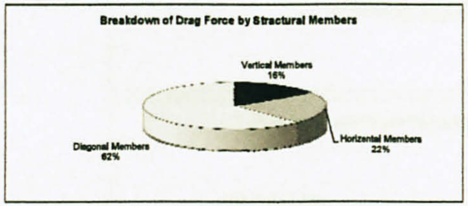
Water Depth(m)	Water Particle Velocity (m/s)	Drag force-FD (N)/m	Drag force-FD (N)/leg
0.24	0.24	0.068	0.009
0.21	0.20	0.049	0.011
0.18	0.20	0.049	0.010
0.15	0.15	0.027	0.006
0.12	0.13	0.021	0.005
0.09	0.12	0.017	0.004
0.06	0.11	0.015	0.003
0.03	0.10	0.013	0.003
-	-	-	-
Total			0.060

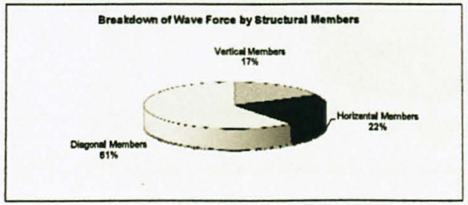
Total Drag Force= 0.080 N

WAVE FORCE

Member	Inertia Force (N)	Drag Force (N)	Wave Force (N)
Vertical Members	0.0043	0.0123	0.02
Horizontal Members	0.0027	0.0177	0.02
Diagonal Members	0.0078	0.0497	0.06
Total	0.0148	0.0798	0.09



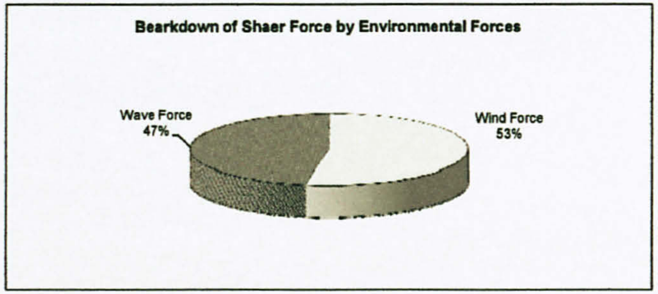


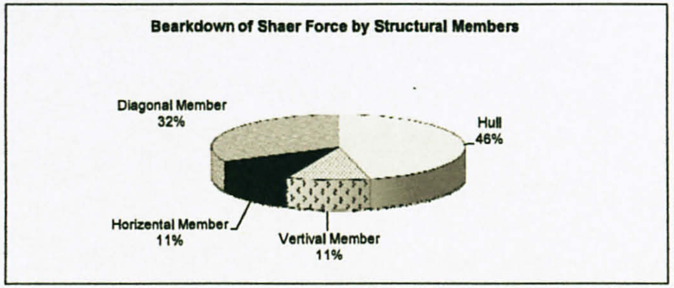


Title: West Prospero-Shear Force
Type of Platform: Jack up offshore structure- West Prospero Model
Location: Malaysia's Jerneh and Tapis fields, off east coast peninsular Malaysia
Done by: Sanam Aghdamy/6154
Date of Modification: 03.04.2008

SHAER FORCE

Type of Force	Hull (N)	Vertival Member (N)	Horizental Member (N)	Diagonal Member (N)	Total (N)
Wind Force	0.092	0.005	0.002	0.007	0.106
Wave Force	-	0.017	0.020	0.058	0.095
Shear Force	**0.092**	**0.021**	**0.022**	**0.065**	**0.200**





Appendix C

BASFJOSEL Output for MSL Model

Type of Platform:	Inputs Jack up offshore structure- MSL Limited Ltd.	
Location:	North Sea	
Done by:	Sanam Aghdamy/6154	
Date of Modification	22.03.2008	

GIVEN DATA:

DIMENSIONS OF PLATFORM:

Hull:

Type of hall: 0
Length= 80 m
Width= 72 m
Depth= 16 m

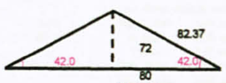


Figure 1

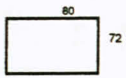
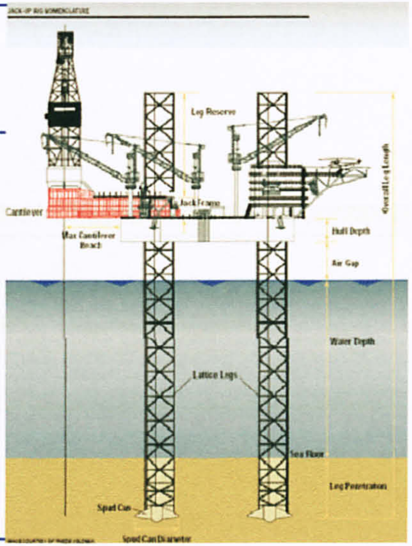


Figure 2

Figure 1 shows the plan view of hull



Leg:

Number of legs= 3
Type of Legs/ Number of chords= 0 3
Usable leg below hull(Including spud can)= 130 m
Leg penetration= 23 m
Overal leg length(Including spud can)= 146 m
Leg length bellow WL(Including spud can) 119.6 m
Leg length above WL(air gap) 10.4 m
Leg spacing= Transverse: 38.9 m
Longitudinal: 38.9 m
Total 55.01 m
Diameter of vertical member= 0.85 m

Lengths of horizental member (For leg type 0 & 1 only)=

L-1(m)	L-2(m)
12.2	12.2

Diameter of horizental member (For leg type 0 & 1 only)= 0.6 m

Length of diagonal member (For leg type 0 & 1 only)=

L-3(m)	L- 4(m)
9.3	9.3

Diameter of diaginal member (For leg type 0 & 1 only)= 0.6 m

Angles of diagonal member with horizental (For leg type 0 & 1 only)=

L-3(m)	L- 4(m)
48.8	48.8

Vertical spacing between horizental members(For leg type 0 & 1 only)= 6.96 m

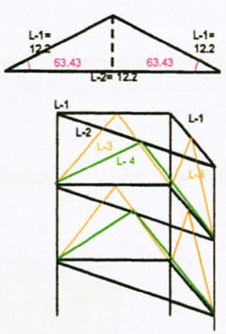


Figure 3

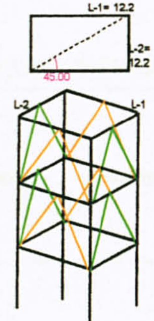


Figure 4

Figure 5

Figure 3 shows the plan view and side view of leg

Spud can:

Spud can diameter= 14.33 m

ENVIRONMENTAL PARAMETERS:

Water depth including storm surge 96.6 m
Maximum wave height 31.2 m
Period of the 100-year wave 17.7 sec
Associated current speed at the surface 0.67 m/sec

Maximum wind speed at 10m above SWL 40.1 m/sec
Soil type Sand
Density of water= 1028 Kg/m^3 when temperature= 15.6 °C
Density of air= 1.225 Kg/m^3 when temperature= 15 °C
Direction of wind= Default

Marine growth (m)=

Between	0	to	-45.72	0.0381
Between	-45.72	to	-96.6	0

μ= 0.001002 $N.Sec/m^2$ when temperature= 15 °C
C_s (top side)= 1.5
C_s (Dry part)= 0.5
C_M = 1.5
C_D = 0.7

CALCULATED INPUT:

WAVE CHARACTERISTICS:

L_o=	489.14 m						
L=	433.18 m						
d/L=	0.2230 Transitional water						
Wave length=	433.18 m						
Wave Speed=	24.47 m/s						
Group number, n=	0.67						
Max. water particle velocityat SWL:			Max. water particle velocityat sea-bed=				
Horizental=	6.25 m/s	Z= 0	Horizental=	2.90 m/s	Z=	-96.6	
Vertical=	0 m/s	θ= 0	Vertical=	0.00 m/s	θ=	0	
Total=	6.25 m/s		Total=	2.90 m/s			
Max. water particle acceleration at SWL=			Max. water particle acceleration atsea-bed=				
Horizental=	0.00 m/s^2		Horizental=	0.00 m/s^2			
Vertical=	1.97 m/s^2		Vertical=	0.00 m/s^2			
Total=	1.97 m/s^2		Total=	0.00 m/s^2			
K_I=	0.44						
K_D=	0.17						

OTHERS:

Number of Memebrs:

No. of vertical members=	9		
No. of horizental braces=	153		
No of horizental braces above WL=	18		
No of horizental braces bellow WL=	135		
No. of diagonal braces=	288		
No of diagonal braces above WL=	18		
No of diagonal braces partially submerged =	1	Length of each brace that is not submerged(L3)- 4.57	Length of brace that is submerged(4.68
		Length of each brace that is not submerg 4.57	Length of brace that is submerge 4.68
No of diagonal braces Fully submerged =	269		
No. of Spudcan=	3		

Exposed Areas:

Wind exposed area:	Area (m2)	No.	Total (m2)
Hull=	1280	1	1280
Vertical member=	9	9	80
Horizental braces=	7	6	44
diagonal braces=	6	36	200
TOTAL=			1603

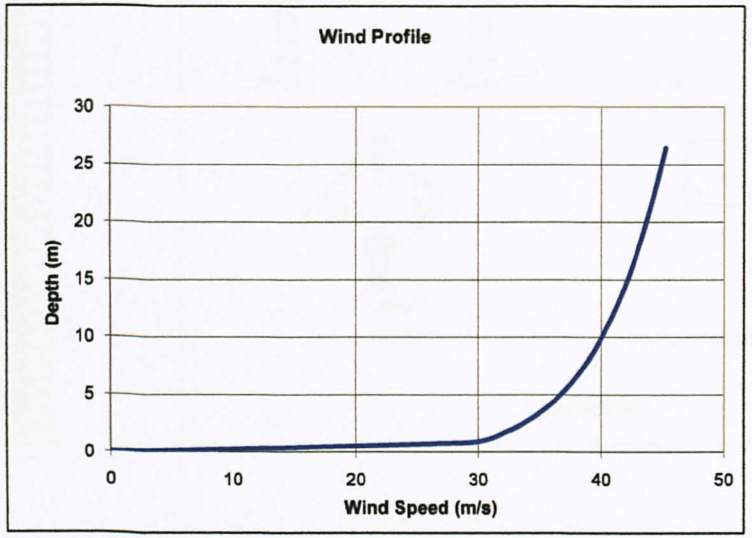
Wave & Current exposed area:	Hieght (m)		Area (m2)	No	Total (m2)
	From	To			
Vertical member=	0	-46	40.60	9	365.44
	-46	-97	43.25	9	389.23
Horizental braces=	0	-46	7.78	21	163.48
	-46	-97	7.32	24	175.68
Diagonal braces=	0	-46	5.91	108	637.79
	-46	-97	5.55	144	799.62
TOTAL=					2531

Title:	Wind Profile
Type of Platform:	Jack up offshore structure- MSL Limited Ltd.
Location:	North Sea
Done by:	Sanam Aghdamy/6154
Date of Modification:	22.03.2008

WIND PROFILE:

Total Heigth above WL= 26.4 m
Selected height internal= 0.88 m
Wind at 10m above WL= 40.1 m/sec
n= 8

Height(m)	Wind speed(m/sec)
26.40	45.27
25.52	45.08
24.64	44.88
23.76	44.68
22.88	44.47
22.00	44.25
21.12	44.03
20.24	43.79
19.36	43.55
18.48	43.30
17.60	43.04
16.72	42.76
15.84	42.47
14.96	42.17
14.08	41.85
13.20	41.52
12.32	41.16
11.44	40.78
10.56	40.37
9.68	39.94
8.80	39.46
7.92	38.95
7.04	38.38
6.16	37.74
5.28	37.02
4.40	36.19
3.52	35.19
2.64	33.95
1.76	32.27
0.88	29.59
0.00	0.00

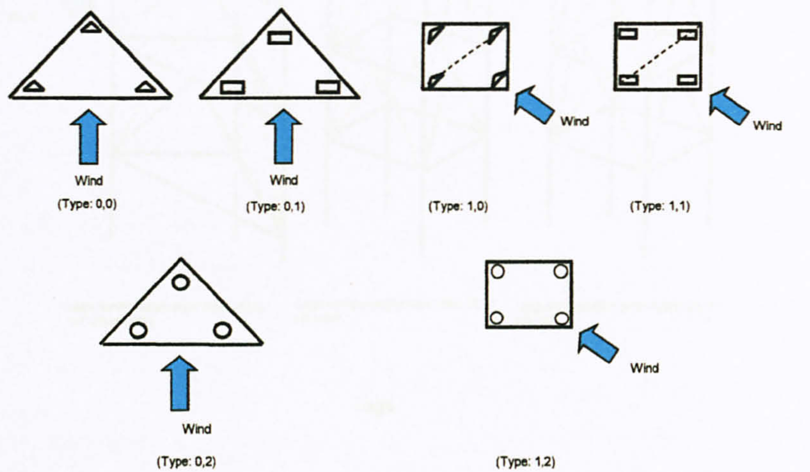


Title:	Wind Force
Type of Platform:	Jack up offshore structure- MSL Limited Ltd.
Location:	North Sea
Done by:	Sanam Aghdamy/6154
Date of Modification:	22.03.2008

OUTPUT:

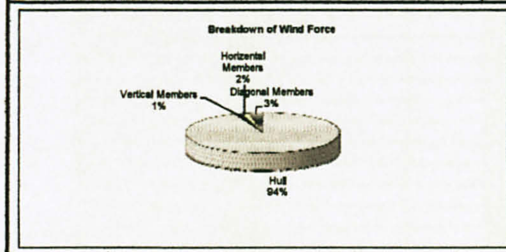
WIND FORCE:

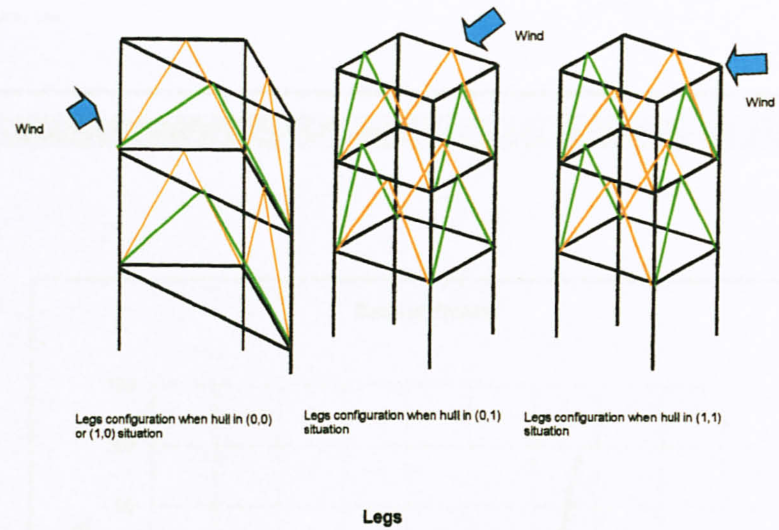
Wind Force			
Height (m)		Wind Velocity (m/Sec)	Force (MN)
From	To		Total
25.52	26.40	45.27	0.133
			0.000
24.64	25.52	45.08	0.131
			0.000
23.76	24.64	44.88	0.130
			0.000
22.88	23.76	44.68	0.129
			0.000
22.00	22.88	44.47	0.128
			0.000
21.12	22.00	44.25	0.127
			0.000
20.24	21.12	44.03	0.125
			0.000
19.36	20.24	43.79	0.124
			0.000
18.48	19.36	43.55	0.123
			0.000
17.60	18.48	43.30	0.121
			0.000
16.72	17.60	43.04	0.120
			0.000
15.84	16.72	42.76	0.118
			0.000
14.96	15.84	42.47	0.117
			0.000
14.08	14.96	42.17	0.115
			0.000
13.20	14.08	41.85	0.113
			0.000
12.32	13.20	41.52	0.111
			0.000



Top side/Hull

11.44	12.32	41.16	0.110
			0.000
10.56	11.44	40.78	0.108
			0.000
9.68	10.56	40.37	0.105
			0.000
8.80	9.68	39.94	0.000
			0.022
7.92	8.80	39.46	0.000
			0.011
7.04	7.92	38.95	0.000
			0.021
6.16	7.04	38.38	0.000
			0.011
5.28	6.16	37.74	0.000
			0.020
4.40	5.28	37.02	0.000
			0.010
3.52	4.40	36.19	0.000
			0.018
2.64	3.52	35.19	0.000
			0.009
1.76	2.64	33.95	0.000
			0.008
0.88	1.76	32.27	0.000
			0.008
0.00	0.88	29.59	0.000
			0.006
Total Force (MN)=			**2.433**
Total Force act on the Hull (MN)=			2.289
Total Forces act on Leg (MN)=			0.145
Total Force act on the vertical member (MN)=			0.030
Total Force act on the Horizental I member (MN)=			0.039
Total Force act on the diagonal I member (MN)=			0.075



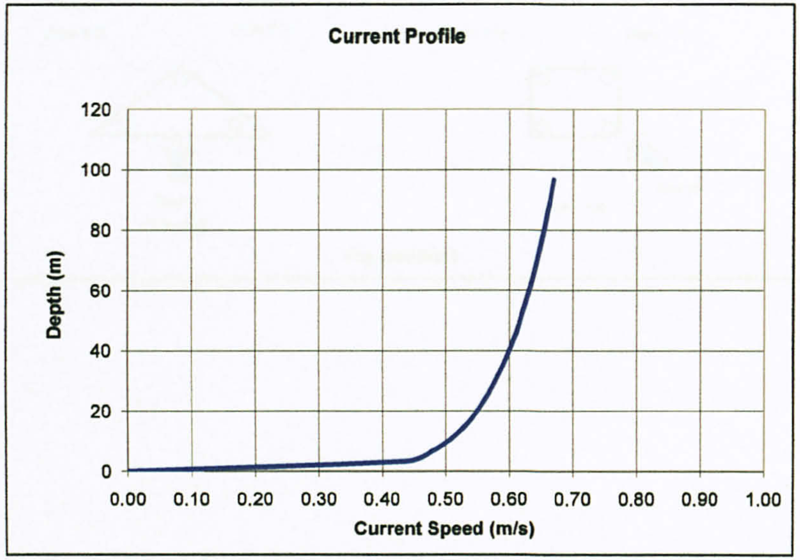


Title:	Current Profile
Type of Platform:	Jack up offshore structure- MSL Limited Ltd.
Location:	North Sea
Done by:	Sanam Aghdamy/6154
Date of Modification:	24.03.2008

CURRENT PROFILE:

Water depth= 96.6 m
Selected height internal= 3.22 m
Associated current speed at the surface= 0.67 m/sec
n= 8

Depth(m)	Current speed(m/sec)
96.60	0.67
93.38	0.67
90.16	0.66
86.94	0.66
83.72	0.66
80.50	0.65
77.28	0.65
74.06	0.65
70.84	0.64
67.62	0.64
64.40	0.64
61.18	0.63
57.96	0.63
54.74	0.62
51.52	0.62
48.30	0.61
45.08	0.61
41.86	0.60
38.64	0.60
35.42	0.59
32.20	0.58
28.98	0.58
25.76	0.57
22.54	0.56
19.32	0.55
16.10	0.54
12.88	0.52
9.66	0.50
6.44	0.48
3.22	0.44
0.00	0.00

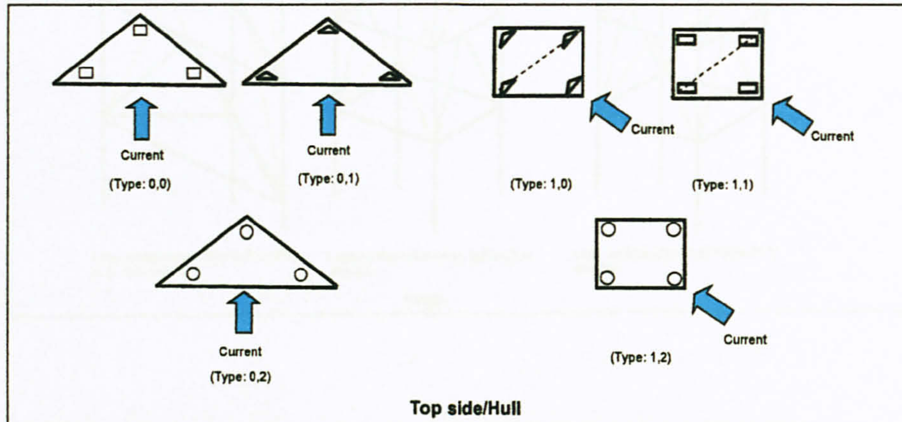


Title:	Current Force
Type of Platform:	Jack up offshore structure- MSL Limited Ltd.
Location:	North Sea
Done by:	Sanam Aghdamy/6154
Date of Modification:	24.03.2008

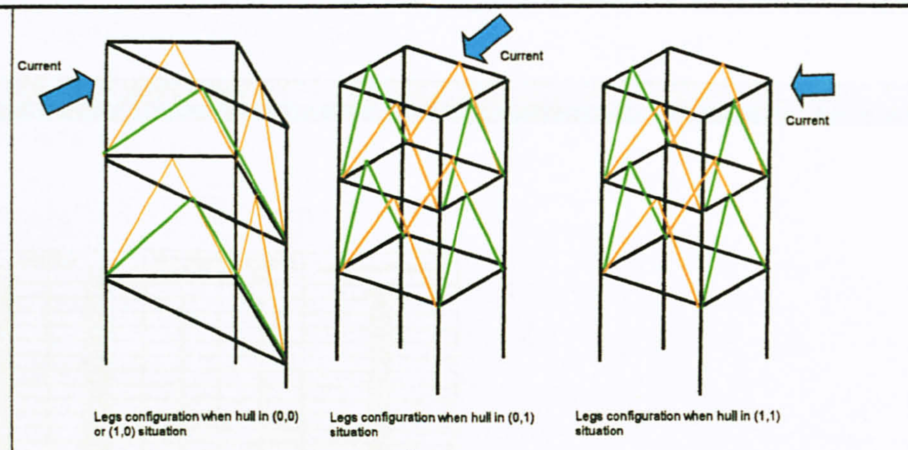
OUTPUT:

CURRENT FORCE:

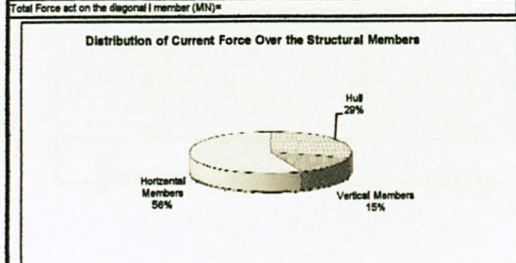
Current Force			
Height (m)		Current Velocity (m/Sec)	Force (MN)
From	To		Total
93.38	96.60	0.67	0.01610236
90.16	93.38	0.67	0.01596646
86.94	90.16	0.66	0.01582700
83.72	86.94	0.66	0.01200974
80.50	83.72	0.66	0.01553648
77.28	80.50	0.65	0.01178088
74.06	77.28	0.65	0.01522867
70.84	74.06	0.65	0.01153784
67.62	70.84	0.64	0.01490098
64.40	67.62	0.64	0.01127840
61.18	64.40	0.64	0.01455012



57.96	61.18	0.63	0.01099971
54.74	57.96	0.63	0.01417187
51.52	54.74	0.62	0.01069806
48.30	51.52	0.62	0.01053714
45.08	48.30	0.61	0.01354042
41.86	45.08	0.61	0.00928479
38.64	41.86	0.60	0.01217481
35.42	38.64	0.60	0.00893378
32.20	35.42	0.59	0.01167682
28.98	32.20	0.58	0.00853572
25.76	28.98	0.58	0.01110547
22.54	25.76	0.57	0.00807258
19.32	22.54	0.56	0.01042919
16.10	19.32	0.55	0.00751238
12.88	16.10	0.54	0.00958780
9.66	12.88	0.52	0.00678820
6.44	9.66	0.50	0.00631714
3.22	6.44	0.48	0.00762489
0.00	3.22	0.44	0.00641175
Total Force (MN)=			**0.33912**
Total Force act on the vertical member (MN)=			0.09958
Total Force act on the Horizental l member (MN)=			0.04917
Total Force act on the diagonal l member (MN)=			0.19038



Legs



Title: Wave Force
Type of Platform: Jack up offshore structure- MSL Limited Ltd.
Location: North Sea
Done by: Sanam Aghdamy/6154
Date of Modification: 03.04.2008

WAVE FORCE

INERTIA FORCE-Fi

For Vertical Member:

Fi= 0.13 MN

For Horizental Member:

Water Depth(m)	Water Particle Acceleration (m/s^2)	Inertia force-Fi (MN)/m	Length(m)		No of member at each level		Inertia force-Fi (MN)/leg
			L-1	L-2	L-1	L-2	
93.08	1.85	0.0009	12.20	12.20	2	1	**0.03**
86.12	1.65	0.0008	12.20	12.20	2	1	**0.03**
79.16	1.46	0.0007	12.20	12.20	2	1	**0.03**
72.20	1.29	0.0006	12.20	12.20	2	1	**0.02**
65.24	1.13	0.0006	12.20	12.20	2	1	**0.02**
58.28	0.98	0.0005	12.20	12.20	2	1	**0.02**
51.32	0.84	0.0004	12.20	12.20	2	1	**0.02**
44.36	0.71	0.0004	12.20	12.20	2	1	**0.01**
37.40	0.59	0.0003	12.20	12.20	2	1	**0.01**
30.44	0.47	0.0002	12.20	12.20	2	1	**0.01**
23.48	0.36	0.0002	12.20	12.20	2	1	**0.01**
16.52	0.25	0.0001	12.20	12.20	2	1	**0.00**
9.56	0.14	0.0001	12.20	12.20	2	1	**0.00**
2.60	0.04	0.0000	12.20	12.20	2	1	**0.00**
-	-	-	-	-	-	-	-
Total							**0.21**

For Diagonal Member:

Water Depth(m)	Water Particle Acceleration (m/s^2)	Inertia force-Fi (MN)/m	Length(m)		No of member at each level		Inertia force-Fi (MN)/leg
			L-3	L-4	L-3	L-4	
89.60	1.75	0.001	9.255	9.255	4	2	0.049
82.64	1.55	0.001	9.255	9.255	4	2	0.043
75.68	1.37	0.001	9.255	9.255	4	2	0.038
68.72	1.21	0.001	9.255	9.255	4	2	0.034
61.76	1.05	0.001	9.255	9.255	4	2	0.030
54.80	0.91	0.000	9.255	9.255	4	2	0.026
47.84	0.77	0.000	9.255	9.255	4	2	0.022
40.88	0.65	0.000	9.255	9.255	4	2	0.018
33.92	0.53	0.000	9.255	9.255	4	2	0.015
26.96	0.41	0.000	9.255	9.255	4	2	0.012
20.00	0.30	0.000	9.255	9.255	4	2	0.009
13.04	0.20	0.000	9.255	9.255	4	2	0.006
6.08	0.09	0.000	9.255	9.255	4	2	0.003
-	-	-	-	-	-	-	-
Total							0.304

Total Inertia Force= 0.646 MN MN

DRAG FORCE-F_D

For Vertical Member:

F_D= 0.51 MN

For Horizental Member:

Water Depth(m)	Water Particle Velocity (m/s)	Drag force-F_D (MN)/m	Length(m)		No of member at each level		Drag force-FD (MN)/leg
			L-1	L-2	L-1	L-2	
93.08	5.98	0.008	12.20	12.20	2	1	0.30
86.12	5.48	0.007	12.20	12.20	2	1	0.25
79.16	5.04	0.006	12.20	12.20	2	1	0.21
72.20	4.65	0.005	12.20	12.20	2	1	0.18
65.24	4.30	0.004	12.20	12.20	2	1	0.16
58.28	4.01	0.004	12.20	12.20	2	1	0.13
51.32	3.75	0.003	12.20	12.20	2	1	0.12
44.36	3.53	0.003	12.20	12.20	2	1	0.10
37.40	3.34	0.003	12.20	12.20	2	1	0.09
30.44	3.19	0.002	12.20	12.20	2	1	0.09
23.48	3.07	0.002	12.20	12.20	2	1	0.08
16.52	2.99	0.002	12.20	12.20	2	1	0.08
9.56	2.93	0.002	12.20	12.20	2	1	0.07
2.60	2.91	0.002	12.20	12.20	2	1	0.07
-	-	-	-	-	-	-	-
Total							1.94

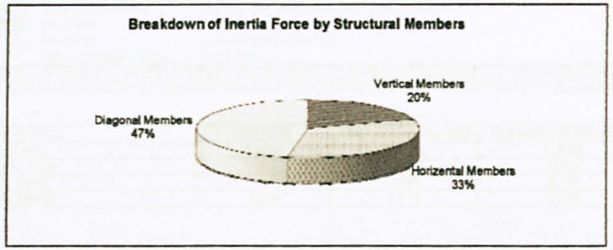
For Diagonal Member:

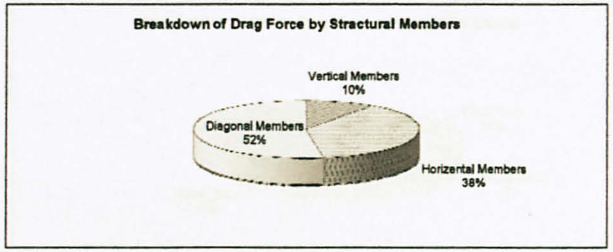
Water Depth(m)	Water Particle Velocity (m/s)	Drag force-FD (MN)/m	Length(m)		No of member at each level		Drag force-FD (MN)/leg
			L-3	L-4	L-3	L-4	
89.60	5.72	0.008	9.255	9.255	4	2	0.278
82.64	5.25	0.006	9.255	9.255	4	2	0.386
75.68	5.25	0.006	9.255	9.255	4	2	0.362
68.72	4.47	0.005	9.255	9.255	4	2	0.278
61.76	4.15	0.004	9.255	9.255	4	2	0.238
54.80	3.87	0.003	9.255	9.255	4	2	0.206
47.84	3.63	0.003	9.255	9.255	4	2	0.180
40.88	3.43	0.003	9.255	9.255	4	2	0.160
33.92	3.26	0.002	9.255	9.255	4	2	0.143
26.96	3.13	0.002	9.255	9.255	4	2	0.131
20.00	3.03	0.002	9.255	9.255	4	2	0.121
13.04	2.96	0.002	9.255	9.255	4	2	0.114
6.08	2.92	0.002	9.255	9.255	4	2	0.110
-	-	-	-	-	-	-	-
Total							2.709

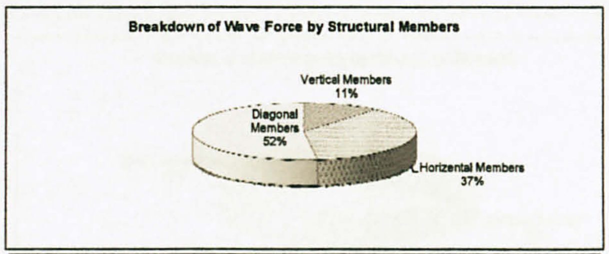
Total Drag Force= **5.158** MN MN

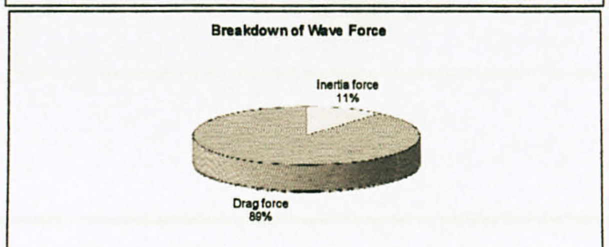
WAVE FORCE

Member	Inertia Force (MN)	Drag Force (MN)					Wave Force (MN)
Vertical Members	0.13	0.51					0.64
Horizental Members	0.21	1.94					2.15
Diagonal Members	0.30	2.709					3.01
Total	0.65	5.16					5.80


Breakdown of Inertia Force by Structural Members
Vertical Members 20%
Diagonal Members 47%
Horizental Members 33%


Breakdown of Drag Force by Stractural Members
Vertical Members 10%
Diagonal Members 52%
Horizental Members 38%


Breakdown of Wave Force by Structural Members
Vertical Members 11%
Diagonal Members 52%
Horizental Members 37%


Breakdown of Wave Force
Inertia force 11%
Drag force 89%

Title: Shear Force
Type of Platform: Jack up offshore structure- MSL Limited Ltd.
Location: North Sea
Done by: Sanam Aghdamy/6154
Date of Modification: 03.04.2008

SHAER FORCE

Type of Force	Hull (MN)	Vertival Member (MN)	Horizental Member (MN)	Diagonal Member (MN)	Total
Wind Force	2.2885	0.0300	0.0393	0.0754	2.433
Current Force	-	0.0996	0.0492	0.1904	0.3391
Wave Force	-	0.641	2.150	3.013	5.804
Shear Force	**2.289**	**0.771**	**2.238**	**3.278**	**8.576**

Bearkdown of Shaer Force by environmental Loads

Bearkdown of Shaer Force by Structural Members

Appendix D

SACS Output for MSL Model

MSL LIMITED PROJECT

****** SEASTATE HYDROSTATIC COLLAPSE ANALYSIS ******

***** DESIGN PARAMETERS ****

DESIGN DEPTH .... 96.600 M.

WATER DENSITY .... 1.028 TONNE/M^3

PRESSURE .... 973.849 KN/M^2

RING HEIGHT INCR........ 1.270 CM.

RING THICK. INCR........ 0.318 CM.

SAFETY FACTOR 2.000

CODE SELECTED .... API

REDESIGN SELECTED ...... NONE

HYDROSTATIC AXIAL LOAD . NO

RING LOCATION .... EXTERNAL

MSL MSL LIMITED PROJECT

****** SEASTATE HYDROSTATIC COLLAPSE ANALYSIS ******

*********** RING PARAMETERS ***********

GROUP LABEL	OUTSIDE DIAMETER (CM)	WALL THICKNESS (CM)	YIELD STRESS (KN/CM2)	HOOP STRESS (KN/CM2)	AXIAL STRESS (KN/CM2)	RING SPACING (CM)	UNITY CHECK
BM1	40.000	2.500	34.500	0.779	0.000	181.02	0.056
CL1	70.000	3.000	38.600	1.136	0.000	382.55	0.097
T1	85.000	4.000	38.600	1.035	0.000	443.31	0.084
T2	60.000	1.600	38.600	1.826	0.000	415.69	0.265

MSL MSL LIMITED PROJECT

** USER SUPPLIED LOAD CASE DESCRIPTIONS **

LOAD CASE DESCRIPTION

1	COMPUTER GENERATED SELF WEIGHT
2	WIND
40	OPR WAVE & CURRENT AT 0.0 DEG
41	OPR WAVE & CURRENT AT 54.0 DEG
42	OPR WAVE & CURRENT AT 90.0 DEG
43	OPR WAVE & CURRENT AT 126.0 DEG
44	OPR WAVE & CURRENT AT 180.0 DEG
45	OPR WAVE & CURRENT AT 234.0 DEG
46	OPR WAVE & CURRENT AT 270.0 DEG
47	OPR WAVE & CURRENT AT 306.0 DEG
50	100-YEAR WAVE & CURRENT @ 0.0 DEG
51	100-YEAR WAVE & CURRENT @ 54.0 DEG
52	100-YEAR WAVE & CURRENT @ 90.0 DEG
53	100-YEAR WAVE & CURRENT @ 126.0 DEG
54	100-YEAR WAVE & CURRENT @ 180.0 DEG
55	100-YEAR WAVE & CURRENT @ 234.0 DEG
56	100-YEAR WAVE & CURRENT @ 270.0 DEG
57	100-YEAR WAVE & CURRENT @ 306.0 DEG

MSL MSL LIMITED PROJECT

**** DEAD LOAD DESCRIPTION FOR LOAD CASE 1 ****

COMPUTER GENERATED SELF WEIGHT

GRAVITY IN -Z DIRECTION

WATER DEPTH *********** 41.10 M

MUDLINE ELEVATION ***** -41.10 M

WATER DENSITY ********* 1.020 TONNE/M^3

BUOYANCY BY MARINE METHOD

INCLUDE BUOYANCY BELOW MUDLINE.NO

MSL MSL LIMITED PROJECT

**** WIND DESCRIPTION FOR LOAD CASE 2 ****

WIND

WIND VELOCITY ************ 40.100 M/SEC

WIND DIRECTION *********** 180.000 DEGREES

WATER DEPTH ************** 41.100 M

REFERENCE HEIGHT ********* 10.000 M

VARIATION EXPONENT ******* 1/08

WIND VARIATION WITH HEIGHT ACCORDING TO API RULES

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 40 ****

OPR WAVE & CURRENT AT 0.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	0.000
19.32	0.550	0.000
38.64	0.600	0.000
57.96	0.630	0.000
77.28	0.650	0.000
96.60	0.670	0.000

**** CURRENT DESCRIPTION FOR LOAD CASE 40 ****

OPR WAVE & CURRENT AT 0.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	0.000
19.32	0.550	0.000
38.64	0.600	0.000
57.96	0.630	0.000
77.28	0.650	0.000
96.60	0.670	0.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 40 ****

OPR WAVE & CURRENT AT 0.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 31.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 18.137 SECS

WAVE LENGTH ************ 448.987 M

ANGLE FROM X TOWARD Y ** 0.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 24.755 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 17.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 112.20 M

TROUGH WATER DEPTH ***** 81.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 41 ****

OPR WAVE & CURRENT AT 54.0 DEG

*MUDLINE ELEVATION *** -41.10 M*

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	54.000
19.32	0.550	54.000
38.64	0.600	54.000
57.96	0.630	54.000
77.28	0.650	54.000
96.60	0.670	54.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 42 ****

OPR WAVE & CURRENT AT 90.0 DEG

WAVE THEORY ************	AIRY	MIN. NO. SEG/MEMBER ****	1
WAVE HEIGHT ************	31.200 M	UNMODIFIED WAVE PERIOD	17.700 SECS
WATER DEPTH ************	96.600 M	STARTING CREST POSITION	0.000 M
WAVE PERIOD ************	18.137 SECS	NO. STEPS **************	36
WAVE LENGTH ************	448.987 M	STEP SIZE **************	10.000 M
ANGLE FROM X TOWARD Y **	90.000 DEGREES	CONVECTIVE ACCELERATION TERMS EXCLUDED	
MUDLINE ELEVATION ******	-41.100 M	CREST WATER DEPTH ******	112.20 M
WAVE CELERITY **********	24.755 M /SEC	TROUGH WATER DEPTH *****	81.00 M
MAX. NO. SEG/MEMBER ****	10		

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 43 ****

OPR WAVE & CURRENT AT 126.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	126.000
19.32	0.550	126.000
38.64	0.600	126.000
57.96	0.630	126.000
77.28	0.650	126.000
96.60	0.670	126.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 43 ****

OPR WAVE & CURRENT AT 126.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 31.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 18.137 SECS

WAVE LENGTH ************ 448.987 M

ANGLE FROM X TOWARD Y ** 126.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 24.755 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 17.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 112.20 M

TROUGH WATER DEPTH ***** 81.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 44 ****

OPR WAVE & CURRENT AT 180.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	180.000
19.32	0.550	180.000
38.64	0.600	180.000
57.96	0.630	180.000
77.28	0.650	180.000
96.60	0.670	180.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 44 ****

OPR WAVE & CURRENT AT 180.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 31.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 18.137 SECS

WAVE LENGTH ************ 448.987 M

ANGLE FROM X TOWARD Y ** 180.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 24.755 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 17.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 112.20 M

TROUGH WATER DEPTH ***** 81.00 M

MSL MSL LIMITED PROJECT

***** CURRENT DESCRIPTION FOR LOAD CASE 45 *****

OPR WAVE & CURRENT AT 234.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	1 CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	234.000
19.32	0.550	234.000
38.64	0.600	234.000
57.96	0.630	234.000
77.28	0.650	234.000
96.60	0.670	234.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 45 ****

OPR WAVE & CURRENT AT 234.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 31.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 18.137 SECS

WAVE LENGTH ************ 448.987 M

ANGLE FROM X TOWARD Y ** 234.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 24.755 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 17.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 112.20 M

TROUGH WATER DEPTH ***** 81.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 46 ****

OPR WAVE & CURRENT AT 270.0 DEG

*MUDLINE ELEVATION *** -41.10 M*

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	270.000
19.32	0.550	270.000
38.64	0.600	270.000
57.96	0.630	270.000
77.28	0.650	270.000
96.60	0.670	270.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 46 ****

OPR WAVE & CURRENT AT 270.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 31.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 18.137 SECS

WAVE LENGTH ************ 448.987 M

ANGLE FROM X TOWARD Y ** 270.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 24.755 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 17.700 SEC

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 112.20 M

TROUGH WATER DEPTH ***** 81.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 47 ****

OPR WAVE & CURRENT AT 306.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	306.000
19.32	0.550	306.000
38.64	0.600	306.000
57.96	0.630	306.000
77.28	0.650	306.000
96.60	0.670	306.000

**** WAVE DESCRIPTION FOR LOAD CASE 47 ****

OPR WAVE & CURRENT AT 306.0 DEG

WAVE THEORY ************	AIRY	NO. STEPS **************	36
WAVE HEIGHT ************	31.200 M	STEP SIZE **************	10.000 M
WATER DEPTH ************	96.600 M	CONVECTIVE ACCELERATION TERMS EXCLUDED	
WAVE PERIOD ************	18.137 SECS	CREST WATER DEPTH ******	112.20 M
WAVE LENGTH ************	448.987 M	TROUGH WATER DEPTH *****	81.00 M
ANGLE FROM X TOWARD Y **	306.000 DEGREES		
MUDLINE ELEVATION ******	-41.100 M		
WAVE CELERITY **********	24.755 M /SEC		
MAX. NO. SEG/MEMBER ****	10		
MIN. NO. SEG/MEMBER ****	1		
UNMODIFIED WAVE PERIOD	17.700 SECS		
STARTING CREST POSITION	0.000 M		

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 50 ****

100-YEAR WAVE & CURRENT @ 0.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	0.000
19.32	0.400	0.000
38.64	0.600	0.000
57.96	1.300	0.000
77.28	1.600	0.000
96.60	1.700	0.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 50 ****

100-YEAR WAVE & CURRENT @ 0.0 DEG

WAVE THEORY ************	AIRY	NO. STEPS **************	36
WAVE HEIGHT ************	51.200 M	STEP SIZE **************	10.000 M
WATER DEPTH ************	96.600 M	CONVECTIVE ACCELERATION TERMS EXCLUDED	
WAVE PERIOD ************	28.767 SECS	CREST WATER DEPTH ******	122.20 M
WAVE LENGTH ************	815.732 M	TROUGH WATER DEPTH *****	71.00 M
ANGLE FROM X TOWARD Y **	0.000 DEGREES		
MUDLINE ELEVATION ******	-41.100 M		
WAVE CELERITY **********	28.356 M /SEC		
MAX. NO. SEG/MEMBER ****	10		
MIN. NO. SEG/MEMBER ****	1		
UNMODIFIED WAVE PERIOD	27.700 SECS		
STARTING CREST POSITION	0.000 M		

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 51 ****

100-YEAR WAVE & CURRENT @ 54.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	54.000
19.32	0.400	54.000
38.64	0.600	54.000
57.96	1.300	54.000
77.28	1.600	54.000
96.60	1.700	54.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 51 ****

100-YEAR WAVE & CURRENT @ 54.0 DEG

WAVE THEORY ************	AIRY	NO. STEPS **************	36
WAVE HEIGHT ************	51.200 M	STEP SIZE **************	10.000 M
WATER DEPTH ************	96.600 M	CONVECTIVE ACCELERATION TERMS EXCLUDED	
WAVE PERIOD ************	28.767 SECS	CREST WATER DEPTH ******	122.20 M
WAVE LENGTH ************	815.732 M	TROUGH WATER DEPTH *****	71.00 M
ANGLE FROM X TOWARD Y **	54.000 DEGREES		
MUDLINE ELEVATION ******	-41.100 M		
WAVE CELERITY **********	28.356 M /SEC		
MAX. NO. SEG/MEMBER ****	10		
MIN. NO. SEG/MEMBER ****	1		
UNMODIFIED WAVE PERIOD	27.700 SECS		
STARTING CREST POSITION	0.000 M		

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 52 ****

100-YEAR WAVE & CURRENT @ 90.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	90.000
19.32	0.400	90.000
38.64	0.600	90.000
57.96	1.300	90.000
77.28	1.600	90.000
96.60	1.700	90.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 52 ****

100-YEAR WAVE & CURRENT @ 90.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 51.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 28.767 SECS

WAVE LENGTH ************ 815.732 M

ANGLE FROM X TOWARD Y ** 90.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 28.356 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 27.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 122.20 M

TROUGH WATER DEPTH ***** 71.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 53 ****

100-YEAR WAVE & CURRENT @ 126.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	126.000
19.32	0.400	126.000
38.64	0.600	126.000
57.96	1.300	126.000
77.28	1.600	126.000
96.60	1.700	126.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 53 ****

100-YEAR WAVE & CURRENT @ 126.0 DEG

WAVE THEORY *********** AIRY

WAVE HEIGHT *********** 51.200 M

WATER DEPTH *********** 96.600 M

WAVE PERIOD *********** 28.767 SECS

WAVE LENGTH *********** 815.732 M

ANGLE FROM X TOWARD Y **126.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 28.356 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 27.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************* 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 122.20 M

TROUGH WATER DEPTH ***** 71.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 54 ****

100-YEAR WAVE & CURRENT @ 180.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	180.000
19.32	0.400	180.000
38.64	0.600	180.000
57.96	1.300	180.000
77.28	1.600	180.000
96.60	1.700	180.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 54 ****

100-YEAR WAVE & CURRENT @ 180.0 DEG

WAVE THEORY ************	AIRY	NO. STEPS **************	36
WAVE HEIGHT ************	51.200 M	STEP SIZE **************	10.000 M
WATER DEPTH ************	96.600 M	CONVECTIVE ACCELERATION TERMS EXCLUDED	
WAVE PERIOD ************	28.767 SECS	CREST WATER DEPTH ******	122.20 M
WAVE LENGTH ************	815.732 M	TROUGH WATER DEPTH *****	71.00 M
ANGLE FROM X TOWARD Y **	180.000 DEGREES		
MUDLINE ELEVATION ******	-41.100 M		
WAVE CELERITY **********	28.356 M /SEC		
MAX. NO. SEG/MEMBER ****	10		
MIN. NO. SEG/MEMBER ****	1		
UNMODIFIED WAVE PERIOD	27.700 SECS		
STARTING CREST POSITION	0.000 M		

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 55 ****

100-YEAR WAVE & CURRENT @ 234.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	234.000
19.32	0.400	234.000
38.64	0.600	234.000
57.96	1.300	234.000
77.28	1.600	234.000
96.60	1.700	234.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 55 ****

100-YEAR WAVE & CURRENT @ 234.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 51.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 28.767 SECS

WAVE LENGTH ************ 815.732 M

ANGLE FROM X TOWARD Y **234.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 28.356 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 27.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 122.20 M

TROUGH WATER DEPTH ***** 71.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 56 ****

100-YEAR WAVE & CURRENT @ 270.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	270.000
19.32	0.400	270.000
38.64	0.600	270.000
57.96	1.300	270.000
77.28	1.600	270.000
96.60	1.700	270.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 56 ****

100-YEAR WAVE & CURRENT @ 270.0 DEG

WAVE THEORY ************ AIRY

WAVE HEIGHT ************ 51.200 M

WATER DEPTH ************ 96.600 M

WAVE PERIOD ************ 28.767 SECS

WAVE LENGTH ************ 815.732 M

ANGLE FROM X TOWARD Y **270.000 DEGREES

MUDLINE ELEVATION ****** -41.100 M

WAVE CELERITY ********** 28.356 M /SEC

MAX. NO. SEG/MEMBER **** 10

MIN. NO. SEG/MEMBER **** 1

UNMODIFIED WAVE PERIOD 27.700 SECS

STARTING CREST POSITION 0.000 M

NO. STEPS ************** 36

STEP SIZE ************** 10.000 M

CONVECTIVE ACCELERATION TERMS EXCLUDED

CREST WATER DEPTH ****** 122.20 M

TROUGH WATER DEPTH ***** 71.00 M

MSL MSL LIMITED PROJECT

**** CURRENT DESCRIPTION FOR LOAD CASE 57 ****

100-YEAR WAVE & CURRENT @ 306.0 DEG

MUDLINE ELEVATION *** -41.10 M

CREST/TROUGH STRETCHING - NON-LINEAR

APPARENT WAVE PERIOD OPTION SELECTED

ELEVATION ABOVE MUDLINE (M)	CURRENT VELOCITY (M/SEC)	DIRECTION ANGLE (DEGREES)
0.00	0.000	306.000
19.32	0.400	306.000
38.64	0.600	306.000
57.96	1.300	306.000
77.28	1.600	306.000
96.60	1.700	306.000

MSL MSL LIMITED PROJECT

**** WAVE DESCRIPTION FOR LOAD CASE 57 ****

100-YEAR WAVE & CURRENT @ 306.0 DEG

WAVE THEORY ************ AIRY	NO. STEPS ************** 36
WAVE HEIGHT ************ 51.200 M	STEP SIZE ************** 10.000 M
WATER DEPTH ************ 96.600 M	CONVECTIVE ACCELERATION TERMS EXCLUDED
WAVE PERIOD ************ 28.767 SECS	CREST WATER DEPTH ****** 122.20 M
WAVE LENGTH ************ 815.732 M	TROUGH WATER DEPTH ***** 71.00 M
ANGLE FROM X TOWARD Y **306.000 DEGREES	
MUDLINE ELEVATION ****** -41.100 M	
WAVE CELERITY ********** 28.356 M /SEC	
MAX. NO. SEG/MEMBER **** 10	
MIN. NO. SEG/MEMBER **** 1	
UNMODIFIED WAVE PERIOD 27.700 SECS	
STARTING CREST POSITION 0.000 M	

MSL MSL LIMITED PROJECT

****** SEASTATE BASIC LOAD CASE SUMMARY ******

RELATIVE TO MUDLINE ELEVATION

LOAD CASE (KN)	LOAD LABEL (KN)	FX (KN)	FY (KN-M)	FZ (KN-M)	MX (KN-M)	MY (KN)	MZ (KN)	DEAD	LOAD
1	1	0	0	-49882.3	-2678057	2262575	0.00075	99764.46	0
2	2	-2407.75	-10.042	-0.2165	3768.992	-556559	128756.6	0	0
3	40	6782.47	0	-399.628	-26255.3	903966	-368162	0	0
4	41	4161.053	5681.025	26.8855	-755832	547334.1	17178.91	0	0
5	42	-18.975	7096.08	-38.4695	-946163	2581.282	330524.9	0	0
6	43	-4074.95	5574.285	-275.979	-753176	-517471	462460	0	0
7	44	-6700.34	-0.0005	-1405.28	-73184.9	-699219	319028.1	0	0
8	45	-3347.96	-4613.12	1364.176	689575.2	-500096	-26275.7	0	0
9	46	54.315	-5206.15	-1675.64	600021.1	83836.35	-245752	0	0
10	47	3893.484	-5327.15	-755.73	667530.3	541600.2	-450317	0	0
11	50	22358.6	-0.0005	-303.91	-22076.1	3141023	-1221333	0	0
12	51	13350.76	18218.74	169.5775	-2556971	1865455	68476.96	0	0
13	52	-11.3265	22759.85	103.2085	-3198137	-1397.82	1025039	0	0
14	53	-13275.8	18121.31	-159.418	-2554956	-1846093	1523030	0	0
15	54	-21154.7	-0.0015	-1832.34	-95079.8	-2876548	1162861	0	0
16	55	-11551.5	-15743	-2736.43	2051926	-1489815	-49396.3	0	0
17	56	45.472	-20812.5	-2179.91	2799554	101478.2	-945527	0	0
18	57	13126.7	-17927.6	-900.965	2470239	1872617	-1510989	0	0

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***** SEASTATE COMBINED LOAD CASES *****

COMBINED LOAD CASE	LABEL	BASIC LABEL	PERCENT	DESCRIPTION
19	**OP1**			1.00 * 1 + 1.00 * 2 + 1.30 * 40
		1	100.00	COMPUTER GENERATED SELF WEIGHT
		2	100.00	WIND
		40	130.00	OPR WAVE & CURRENT AT 0.0 DEG
20	**OP2**			1.00 * 1 + 0.71 * 2 + 1.30 * 41
		1	100.00	COMPUTER GENERATED SELF WEIGHT
		2	70.70	WIND
		41	130.00	OPR WAVE & CURRENT AT 54.0 DEG

21 **OP3** 1.00 * 1 + 1.00 * 2 + 1.30 * 42

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 100.00 WIND

42 130.00 OPR WAVE & CURRENT AT 90.0 DEG

22 **OP4** 1.00 * 1 + 0.71 * 2 + 1.30 * 43

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 70.70 WIND

43 130.00 OPR WAVE & CURRENT AT 126.0 DEG

23 **OP5** 1.00 * 1 + -1.00 * 2 + 1.30 * 44

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -100.00 WIND

44 130.00 OPR WAVE & CURRENT AT 180.0 DEG

24 **OP6** 1.00 * 1 + -0.71 * 2 + 1.30 * 45

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -70.70 WIND

45 130.00 OPR WAVE & CURRENT AT 234.0 DEG

25 **OP7** 1.00 * 1 + -1.00 * 2 + 1.30 * 46

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -100.00 WIND

46 130.00 OPR WAVE & CURRENT AT 270.0 DEG

26 **OP8** 1.00 * 1 + -0.71 * 2 + 1.30 * 47

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -70.70 WIND

47 130.00 OPR WAVE & CURRENT AT 306.0 DEG

27	**ST1**	1.00 * 1 + 1.00 * 2 + 1.30 * 40

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 100.00 WIND

40 130.00 OPR WAVE & CURRENT AT 0.0 DEG

28	**ST2**	1.00 * 1 + 0.71 * 2 + 1.30 * 41

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 70.70 WIND

41 130.00 OPR WAVE & CURRENT AT 54.0 DEG

29	**ST3**	1.00 * 1 + 1.00 * 2 + 1.30 * 42

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 100.00 WIND

42 130.00 OPR WAVE & CURRENT AT 90.0 DEG

30 **ST4** 1.00 * 1 + 0.71 * 2 + 1.30 * 43

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 70.70 WIND

43 130.00 OPR WAVE & CURRENT AT 126.0 DEG

31 **ST5** 1.00 * 1 + -1.00 * 2 + 1.30 * 44

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -100.00 WIND

44 130.00 OPR WAVE & CURRENT AT 180.0 DEG

32 **ST6** 1.00 * 1 + -0.71 * 2 + 1.30 * 45

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -70.70 WIND

45 130.00 OPR WAVE & CURRENT AT 234.0 DEG

33	**ST7**	1.00 * 1 + -1.00 * 2 + 1.30 * 46

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -100.00 WIND

46 130.00 OPR WAVE & CURRENT AT 270.0 DEG

34	**ST8**	1.00 * 1 + -0.71 * 2 + 1.30 * 47

1 100.00 COMPUTER GENERATED SELF WEIGHT

2 -70.70 WIND

47 130.00 OPR WAVE & CURRENT AT 306.0 DEG

MSL MSL LIMITED PROJECT

***** SEASTATE COMBINED LOAD CASE SUMMARY *****

RELATIVE TO MUDLINE ELEVATION

LOAD CASE (KN)	LOAD LABEL (KN)	FX (KN)	FY (KN-M)	FZ (KN-M)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
19	OP1	6409.461	-10.042	-50402	-2708419.898	2881172	-349854
20	OP2	3699.866	7378.203	-49847.5	-3657962.616	2578952	113749.8
21	OP3	-2432.42	9214.862	-49932.5	-3904299.908	1709372	558439
22	OP4	-7006.94	7239.441	-50241.2	-3654509.816	1194706	692615.2
23	OP5	-6302.69	10.04135	-51708.9	-2776966.362	1910149	285979.9
24	OP6	-2642.85	-5989.93	-48108.7	-1784285.224	2007607	-125576
25	OP7	2478.36	-6757.95	-52060.4	-1901798.562	2928121	-448234
26	OP8	1709.503	7.12982	-49882.1	2681826.692	2657732	-91417.2
27	ST1	6409.461	-10.042	-50402	-2708419.898	2881172	-349854
28	ST2	3699.866	7378.203	-49847.5	-3657962.616	2578952	113749.8
29	ST3	-2432.42	9214.862	-49932.5	-3904299.908	1709372	558439
30	ST4	-7006.94	7239.441	-50241.2	-3654509.816	1194706	692615.2
31	ST5	-6302.69	10.04135	-51708.9	-2776966.362	1910149	285979.9
32	ST6	-2642.85	-5989.93	-48108.7	-1784285.224	2007607	-125576
33	ST7	2478.36	-6757.95	-52060.4	-1901798.562	2928121	-448234
34	ST8	1709.503	7.12982	-49882.1	2681826.692	2657732	-91417.2